University of Nevada Reno

Sediment Production, Storage, and Transport Processes Studied in Two Semi-Arid Basins and in a Recently Burned Region of the Mojave National Preserve

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by

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Abstract

This research is composed of two studies focused on elucidating processes that effect sediment storage and stability in semi-arid regions. Results indicate that under current climatic conditions hillslope sediment is more resistant to erosional processes than previously believed. Paleoclimate events caused significant episodic mobilization of hillslope sediment, resulting in formation of colluvial aprons and fan-terraces. Hillslope soils were found to be <1 thousand years old, implying that episodic sediment mobilizing events occurred up until ~1 ka. Over the last 1 ka hillslopes have been stable accumulating significant amounts of eolian derived sediment. The second part of the research focused on the impact of vegetation loss due to fire on soil properties and erosion rates of burned hillslopes compared to unburned hillslopes. Even after significant loss of vegetative cover hillslope sediment was found to be less susceptible to erosional processes than previous studies have shown. Results aid in the understanding of geomorphic processes in semi-arid regions.

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Chapter I - Sediment production, storage and transport processes studied in two semi-arid basins and in a recently burned region of the Mojave National Preserve

1. General Introduction

In the last two centuries, arid regions in the United States have been locations of increasing urban and agricultural development. The continued pervasiveness of urban sprawl makes it an important time to step back and look at the natural processes associated with arid-regions, such as, hillslope stability, sediment accumulation, and transport of sediment during precipitation events. All of these processes may result in significant geomorphic hazards that must be considered by developers, land owners, land managers, and preservationists. The relationships between hillslope stability, formation of landforms, and massive movement of sediment have been commonly assumed to be directly related to environmental conditions which alter the vegetative cover on hillslopes, but few large scale studies have been done to comprehend hillslope processes as a whole system (Ahlgren and Ahlgren, 1960; Helvey, 1980; Soler and Sala, 1992; Germanoski and Miller, 1995; Carcaillet et al., 2006; Rulli et al., 2006). Changes in vegetative cover have been shown to be linked to environmental changes, such as a fluctuating climate (Van Devander and Spaulding, 1979; Spaulding, 1990) and can also be influenced by fire and anthropogenic activity (Brooks et al., 2005). The last major climate change in the Mojave Desert occurred during the mid to late Holocene when the climate shifted from a cool moist climate to a warm dry climate. The basins are currently experiencing a warmer dry period than was present during the early Holocene. Previous vegetation studies in the region indicate that vegetation density in the basins has

decreased from the early Holocene and latest Pleistocene to the present day (Van Devander and Spaulding, 1979; Spaulding, 1990).

This research is divided into two studies and sets out to examine the relationship between vegetative change and landform development on a more detailed macro-scale level, in order to increase knowledge of hillslope and geomorphic processes in semi-arid regions. Both studies were completed within the Mojave National Preserve, in southern California (Figure 1). The first study, presented in Chapter II, focuses on sediment distribution and soil development on landforms in two semi-arid basins, with different lithology. A key part of this study was identifying where sediment was stored in the basins prior to formation of landforms and what environmental conditions may have resulted in the transport and deposition of sediment onto the particular landforms. A common hypothesis is that an increase in monsoonal storm activity, coupled with a decrease in vegetation, would have a significant affect on the hillslope soils resulting in substantial sediment loss and rill formation (Bull, 1991).

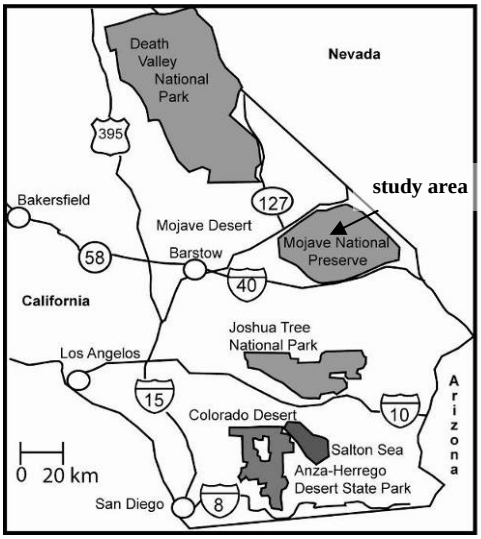

Figure 1. General location of study area.

The second part of this research, presented in Chapter III, focuses on post-fire changes in soil properties, infiltration rates, and sediment stability on burned and unburned hillslopes within two different eco-tones in the Mojave National Preserve. In June 2005, a wildfire burned 284 km^2 in the Mojave National Preserve. This fire provided an opportunity to study the stability of hillslope soils after the loss of significant vegetative cover. Fieldwork was completed in June and September 2006. Erosional features were measured in September 2006, after two consecutive convective storm seasons had passed.

Understanding the relationship between vegetation and slope stability in semi-arid regions has significant implications regarding the possible affects that environmental factors, such as climate change and fire, may have on a region. Most studies completed on vegetation loss and corresponding erosional events have been done on small plot scales, which often lack the size and variation of topography necessary to comprehend what happens when vegetation is removed from a hillslope in a natural setting (Abrahams et al., 1995; Bochet et al., 2006; Shakesby and Doerr, 2006). Research in the Mid Hills region focused on understanding the effect of fire on hillslopes in semi-arid regions by identifying pre- and post-fire erosional features and changes in soil properties over the entire hillslope.

The combination of results from both studies significantly increases the knowledge and understanding of geomorphic processes on hillslopes in semi-arid regions. This work provides new information on soil properties, sediment sources and stability in semi-arid regions, the role of vegetation on hillslope processes, and the rate of

soil development on landforms in semi-arid basins, to the growing body of paleoclimate literature. Results of this work will enhance future efforts that evaluate landform stability, govern development of structures in semi-arid regions, and assist in creation of better land management practices. Determining areas prone to such geomorphic hazards will help avoid the detrimental effects that may occur when environmental factors are altered.

Chapter II - Production, Storage, and Transport of Sediment during Periods of Holocene Climate Change

1. Introduction

The effect of climate transition on periods of production, storage, and transport of sediment in semi-arid basins has been the focus of much speculation by geomorphologists over the last few decades (Wells et al., 1987; Bull, 1991; Harvey and Wells, 1994; McDonald, 1994; Harvey et al., 1999; Reheis, 1999; Riebe, 2001; Harvey et al., 2003; McDonald et al., 2003; McFadden et al. 2005). Questions regarding the identification of soil geomorphic processes occurring within semi-arid basins, especially how basin sediment is stored, and the climatic requirements necessary for transport of sediment out of the basins have yet to be answered. This research focuses on the general relationships between periods of climate change, sediment production, and storage of sediment in semi-arid alluvial basins. Results will advance the understanding of how climate change affects processes in semi-arid basins, which in turn effects the formation of alluvial fans. Fieldwork and soils analysis completed for this research begins to address hypotheses proposed by previous studies (McDonald, 1994; McDonald et al. 1997). New knowledge gained from this research combined with results from previous studies greatly advances the understanding of geomorphic processes in semi-arid basins, although many issues still remain.

The lithologic diversity of the Providence Mountains, located in the Mojave Desert of Southern California, combined with the detailed geomorphic and paleoclimate studies completed in this region provides a unique setting to carry out a detailed study of processes occurring in semi-arid basins. Previous work completed in the Mojave Desert

(Spaulding, 1990; McDonald, 1994; Lancaster, 1997; McDonald et al., 2003) provides extensive knowledge of the geomorphic features in the area and data on regional paleo climatic environments (Ely, 1997; Enzel and Wells, 1997; Lancaster, 1997), this information assists in better elucidating processes occurring in the semi-arid basins. Previous studies of geomorphic land forms have identified the difficulty in determining if the control of geomorphic factors is secondary to the control of climate change in triggering periods of alluvial fan deposition across a region (McDonald et al., 2003). Factors such as tectonic stability, mountain height, basin lithology, and square area of the drainage basin may exert significant influence on alluvial depositional processes (Bull, 1991) and therefore fan deposition (McDonald et al., 2003). If a particular aspect of climate change controls the timing of alluvial fan deposition, than the temporal relationship between fan deposition and variance in climate may occur in a similar way across a region and throughout diverse geomorphic settings (McDonald et al., 2003).

Understanding relationships that occur between vegetation, sedimentation, and slope stability in basin environments during periods of paleoclimate change offers a myriad of challenges that must be addressed when collecting and analyzing data to assure validity of results. Relative age dating of soils is only accurate when there is enough supportive evidence to indicate a relationship between landforms in different basins and periods of aggradation and degradation. Sediment deposited by alluvial processes is inherently hard to date. The most successful work completed on correlating periods of climate change with alluvial fan deposition has been accomplished by studying mountain piedmonts that border pluvial lake basins, which contain datable lacustrine deposits and shoreline features (Wells et al., 1987; Harvey and Wells; 1994, Reheis et al., 1996; Enzel

and Wells, 1997; Harvey et al., 1999). Previous work completed on pluvial lakes in the Mojave desert (Enzel and Wells, 1997; Harvey et al., 1999) support McDonald et al.'s (2003) conclusion that pronounced periods of alluvial fan aggradation in the Mojave Desert are linked to periods of climate change, including climate change associated with the Pleistocene-Holocene transition.

Several conceptual models have been proposed on time-transgressive changes in climate and vegetation during the Pleistocene-Holocene transition, which resulted in intervals of alluvial fan sedimentation. A combination of previous models of sediment mobilization suggest that sediment loss from hillslopes is a simple return function correlated to episodic periods of warming and drying with increases in monsoonal storm activity, which affect the vegetative cover of hillslopes, and consequently impacts slope stability and erosion rates (Bull, 1991). Bull (1991) proposed that when the climate changes from a wet to dry environment a reduction of effective soil moisture occurs resulting in a loss of vegetative cover on hillslopes, thus causing increased soil erosion and a concomitant increase in sediment supply to the alluvial fans.

Harvey and Wells (1994) studied an alluvial fan system located at Zzyzx in the Mojave Desert, California, approximately 64 kilometers northwest of the Providence Mountains. They surmised that during the Pleistocene, which was cooler and wetter than the current climate, there was increased weathering of bedrock resulting in increased sediment production on hillslopes and transport of sediment off hillslopes by mass movement processes resulting in excess sediment supply to the alluvial fans. Harvey and Wells (1994) also suggested that after the Pleistocene-Holocene transition, when the climate is known to have become warm and dry (McDonald et al., 2003), stabilization of

sediment occurred on the hillslopes and erosion of sediment was limited to flashflood events that increased the rate of runoff for short periods of time resulting in fan head trenching and distal fan progradation. Based on these hypotheses Harvey and Wells (1994) proposed that minor changes in paleoclimate activity are recorded in the variations of fan behavior over time.

Work completed on the Providence Mountain piedmont by McDonald (1994) and McDonald et al. (2003) identified geomorphic relationships within alluvial basins that implied alterations in vegetative cover of semi-arid basins during the Pleistocene-Holocene transition had a restricted impact on slope instability and sediment yield based on three hypotheses: (1) coarse textured soils and colluvium are associated with higher infiltration levels, (2) hillslopes have strong spatial variation in soil cover, and (3) modern vegetation appears to provide enough stability for accumulation of soils and colluvium. The hypotheses put forth by McDonald et al. (2003) were considered as part of this research and helped formulate the conceptual model of slope stability and transport of sediment in semi-arid basins that is proposed at the end of this chapter.

Three major hypotheses put forth at the beginning of this project were: (1) significant sediment storage (1 m – 1.5 m) occurs on the basin hillslopes, (2) the oldest soils present in both basins will be early Holocene to late Pleistocene in age, and (3) based on geologic expression and bedrock degradational features, significantly more sediment will be stored in the granite dominated basin than in the limestone dominated basin.

This research set out to examine processes in the Providence Mountain alluvial basins that control sediment production during periods of climate change and affect

sediment storage prior to sediment being mobilized out of the drainage basins and onto the piedmont resulting in formation of alluvial fans. The research concludes in a conceptual model of the integrated processes occurring in the basins and a discussion of the paleoclimatic parameters that would have been necessary to produce the large-scale alluvial fans as seen on the Providence Mountain piedmont. During the course of this research significant amounts of eolian derived sediment were identified in both basins. The source and impact of eolian derived sediment on drainage basin processes was examined as part of this research and was found to have a significant impact on soil development in the basins.

2. Regional Setting

The field site for this study consists of two lithologically varied drainage basin environments, a limestone dominated basin (hereafter the Limestone Basin) and a granite dominated basin (hereafter the Granite Basin) (Appendix 5). McDonald (1994; et al. 2003) mapped the Granite Basin was mapped and labeled as mixed plutonic (PM) and the Limestone Basin, was considered to be dominated by limestone and marble (LS). Both basins are located in the Providence Mountain Range on the eastern edge of the Mojave Desert in southeastern California (Figure 2). The Limestone Basin area (2.68 km^2) is 1.5 times larger than the Granite Basin (1.44 km^2) (Figure 3). The basins are approximately 16 km apart and maintain many similar characteristics including orientation, vegetation, basin floor elevation, and precipitation patterns. The similarity between the basins allows for a comparative study of geomorphic events occurring over time within the semi-arid basins.

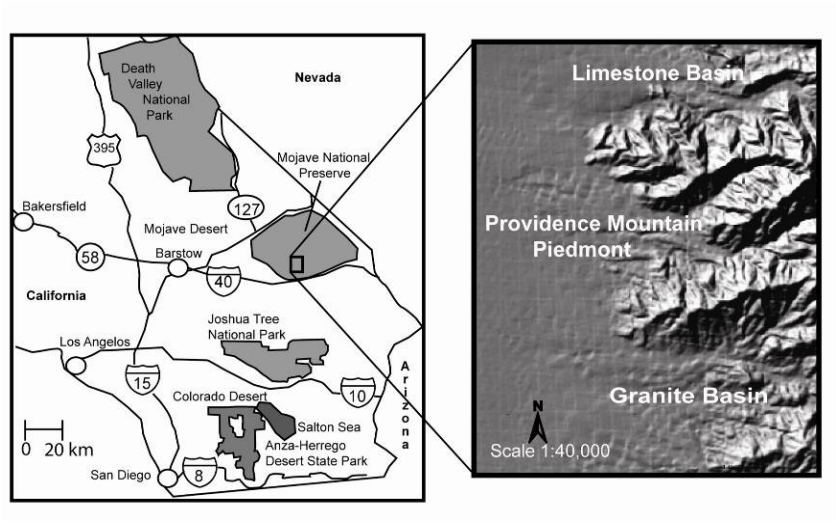

Figure 2. Location of field area with a Hillshade DEM of the alluvial fans and field site locations.

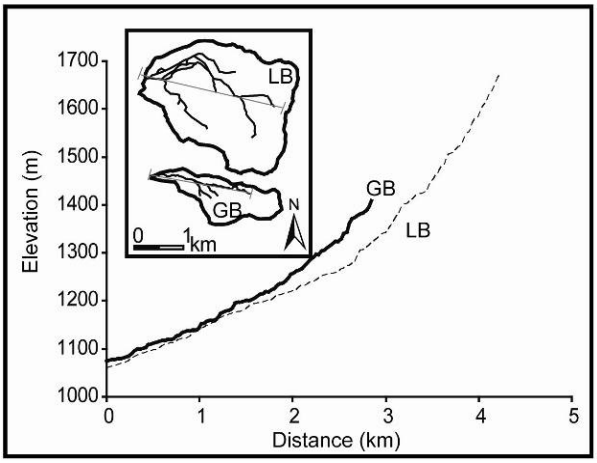

Figure 3. Schematic diagram comparing typical stream profiles of the Granite Basin (1.44 km^2) and the Limestone Basin (2.68 km^2). The graph illustrates the axial drainage profile (1st and 2nd order drainages) for each basin along the transects.

The Providence Mountains are a geologically important boundary, serving as a barrier for wind blowing suspended particles southeast from Devils Playground. The prevailing east-southeast wind direction is opposed by the topographically controlled westerly winds (Ramsey et al., 1999). Sand and fine-grained sediment are transported by prevailing westerlies in the Mojave Desert (Reheis and Kihl, 1995). Reheis et al. (1995)

documented the deposition of dust into the Mojave from upwind sources in southern Nevada and California. The dust documented by Reheis et al. (1995) corresponds to the mineralogical and compositional similarity of Av horizons developed on basalt flows in the Mojave Desert (McFadden, et al., 1998).

Evidence of Mid Tertiary fault activity responsible for the mountain uplifts, is evident in the overturned bedrock of the Limestone Basin (USGS, 2004). Prior tectonic activity in the Limestone Basin appears to have formed an anticline resulting in south facing slopes that have very steep overturned beds dipping 60° to the west where as the bedding planes on the north facing slope dip 10° to the south. Tectonic activity is still occurring in parts of the Providence Mountains and continues to influence landscape development of some areas, but no evidence of tectonic activity after the Tertiary period has been observed in either study basin (i.e. fault scarps) (USGS, 2004).

Axial drainages within both basins have similar elevation gains with distance (Figure 3). Regional precipitation patterns suggest that the base of the alluvial fan sequence (800 - 1000 meters above seal level (m.a.s.l)) receives annual rainfall of 150 mm/yr where as the highest points in the Providence Mountains (2100 m.a.s.l. in the Limestone Basin and 1450 m.a.s.l. in the Granite Basin) receive up to 250 mm/yr (Figure 4).

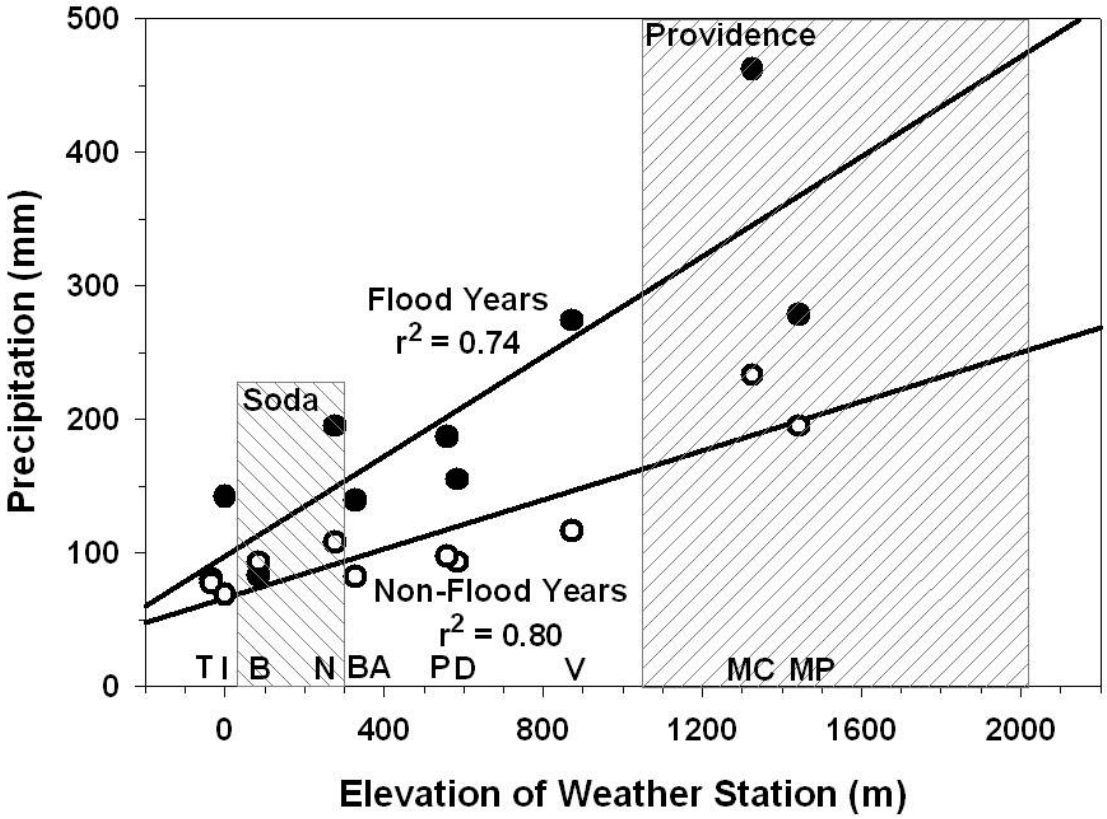

Figure 4. Illustration of regional trends in annual precipitation across southern California deserts based on precipitation records for 1948 – 1999, as presented in McDonald et al. (2003). Flood years (filled circles, upper regression line) represents mean annual precipitation for years when flooding of the Silver Lake Playa occurred (1969, 1978, 1980, 1983, 1992, 1998). Non-flood years represent mean annual precipitation for all non-flood years. Weather data from: T-Thermal, I-indigo, B-Blythe, N-Needles, BA-Baker, P-Twentynine Palms, D-Daggett, V-Victorville, MC-Mitchell Caverns, MP-Mountain Pass.

Currently, the majority of precipitation in the Providence Mountains occurs during the winter and early spring months as Pacific frontal storms (McDonald et al., 2003). The Mojave Desert has been previously exposed to cyclical periods of increased precipitation that are largely linked with the episodic formation of pluvial Lake Mojave (McFadden et al., 1992; Harvey and Wells, 1994; McDonald, 1994; Ely, 1997; Harvey et al., 1999; McDonald et al., 2003), followed by extended dry periods resulting in formation of playas, including Soda and Silver dry lakes (Enzel and Wells 1997). More

precise knowledge regarding the timing of wet and dry pluvial lakebeds has been gained by studying paleoflooding events, which often lasted for greater than a century and have been linked to cooler and wetter climates (Ely, 1997). Lake level in pluvial Lake Mojave was constantly fluctuating from 24 to 9 ka (thousand years ago). After 9 ka pluvial Lake Mojave began to experience repeated periods of wetting and drying, resulting in four significant episodes of drying over the last 10 ky, with each period of drying lasting approximately 2 to 3 ky (Enzel, 1997). These periods were followed by warmer dry episodes resulting in the formation of sand sheets (Qe2 and Qe3 based on McDonald et al., 2003) (Enzel and Wells, 1997) (Figure 5). Based on playa sediments which indicate marsh like conditions it has been determined that periods of pluvial lake activity during the early Holocene lasted approximately 50 to 400 years, with the last significant wetting period occurring approximately 0.4 ka (Enzel and Wells, 1997; McDonald et al., 2003). Over the last century Silver Lake (a terminal playa formed from remnant pluvial Lake Mojave) has formed a pluvial lake greater than 1 m deep five times, none of these lake forming events lasted for more than 18 months (Enzel and Wells, 1997).

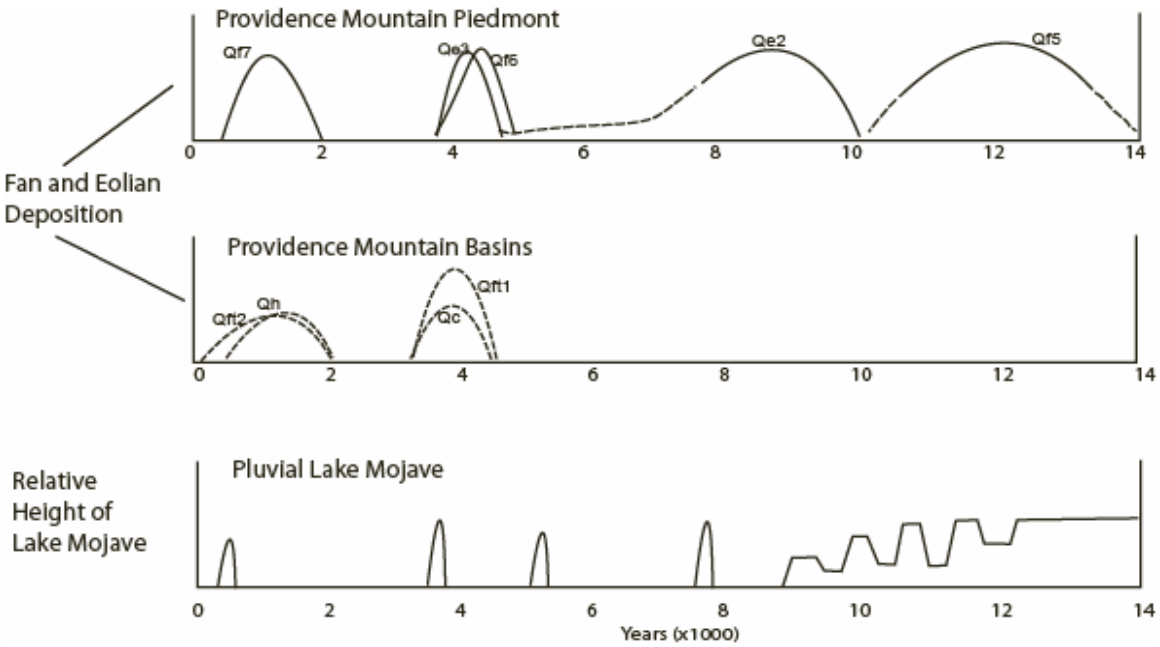

Figure 5. Summary of periods of fan and eolian deposition along the Providence Mountain piedmont and Providence Mountain basins combined with fluctuations of pluvial Lake Mojave. Plots of geomorphic events imply general interval of time and levels of activity over the last 14 ka, but do not imply relative volumes of sediment. Dashed lines are interpolations of events based on field observations. Lake Mojave and Providence Mountain Piedmont figures were adapted from McDonald et al., 2003.

The degree and type of vegetative cover differs significantly in both basins and is highly dependent on slope aspect and elevation. Younger terraces in both basins tend to be dominated by *Larrea tridentata* (creosote-bush), where as hillslope vegetation is dominated by *Cylindropuntia leptocaulis cactaceae* (cholla cacti), *Ferocactus cylindraceus acanthodes* (barrel cactus), *Coleogyne ramosissima* (black brush) and low-lying grasses. Vegetation on the south facing slope in the Limestone Basin is almost completely dominated by *Ferocactus cylindraceus acanthodes*. Juniper and Piñon trees are present on the north facing slopes of both basins, and abundance and size of the trees increases substantially with elevation. *Bromus rubens* (cheatgrass) is present throughout the basin environments, with greater abundance in the Granite Basin.

3. Methodology

Basin landforms were delineated using features such as vegetative cover, soil thickness, slope angle, and landform shape. The geomorphology within each basin was mapped using stereo-pair aerial photography, followed by field mapping to evaluate landform boundaries and to map landforms that were not visible on the aerial photographs (i.e. debris flows, sub-drainages, small colluvial deposits). ArcMap version 9.1 was used for digital mapping of the basins using digital orthophoto quadrangles (DOQs) at a scale of 1:3000 for the Granite Basin and 1:6000 for the Limestone Basin.

Excavation of soil pits was completed on selected landforms throughout both basins to gather information on spatial patterns of soil thickness and obtain knowledge regarding soil development on landforms. The first series of soil pits focused on the excavation of multiple shallow pits in both basins to observe the top 20 to 30 centimeters of soils formed on each landform and identify patterns of soil development. A second set of deeper soil pits was excavated to the C-horizon at strategic locations in both basins with respect to varied slope aspect, slope angle, and geomorphic landforms. Soil profiles were described using standard methods (Birkeland, 1999; Soil Survey Staff, 2003).

Bulk soil samples were collected from each soil horizon of designated soil pits and analyzed for electrical conductivity (EC) (Rhoades, 1996), pH (Thomas, 1996) and particle size using a laser light scattering method (Gee and Or, 2002). Additional field samples were collected from the silt rich horizons of various landforms and submitted along with bedrock samples for X-ray fluorescence (XRF) analysis to establish the source

and influence of eolian sediment within the basins (Whittig and Allardice, 1986; Karathanasis and Hajek, 1996; Johnson et al., 1999).

Age estimates for soils and landforms in the Granite and Limestone Basin are based on correlating soil profiles developed on landforms in the basins to soil development data from the alluvial fans that formed from the Providence Mountain basins (McDonald, 1994; McDonald et al. 2003). A key assumption for soil correlation is that soil formation has occurred at the same relative rates on both the piedmont and within the basins. Correlation of soils between the basins (this study) and alluvial fans (McDonald et al., 2003) is based on overall degree of soil formation and similarities in profile morphology. Correlating the degree of soil development between the alluvial fans, which have been dated using radiometric techniques, and the basin soils allows for ages to be assigned to the various landforms present in the Granite and Limestone Basins.

4. Results

4.1 Distribution of landforms, soil cover, and soil properties within both basins

The basin landforms were subdivided into five categories based on geomorphic mapping and field observations: (1) bedrock outcrops (Bx), (2) talus slopes (Qt), (3) alluvial fan-terraces (Qft), (4) colluvial deposits (Qc), and (5) hillslope mantle (Qh) (Table 1). Geomorphic maps created for each basin illustrate the spatial coverage of the various landforms (Figures 6 and 7). Bedrock outcrops large enough to be seen on the aerial photographs were mapped as predominantly bedrock, although some sediment may exist between outcrops. Talus slopes were recognized as surfaces with slope angles

Table 1. Landform descriptions.

Landform	Map Description
Qft2 - active wash/fan-terrace Late Holocene	Low angle (0º - 20º) fluvial deposits; form terraces along the axial drainages; can be mapped onto the piedmont where they form alluvial fans
Qh - hillslope mantle soil Late Holocene	Thin (<25 cm) mantle of soil over weathered bedrock; significant eolian component
Qc - colluvial deposit Mid to Late Holcoene	Sediment eroded from the hillslopes and deposited onto the fan-terraces
Qft1 - fan-terrace Mid to Late Holcoene	Low angle (0º - 20º) fluvial deposits:form terraces along the axial drainages; can be mapped onto the piedmont where they form alluvial fans
Qt - talus slopes	Surfaces with slope angles ranging from 20° – 50°, minimal vegetative cover, commonly forming below bedrock outcrops; only present in the Limestone Basin
Bx - bedrock	Outcrops of exposed bedrock, some patchy sediment may exist between outcrops

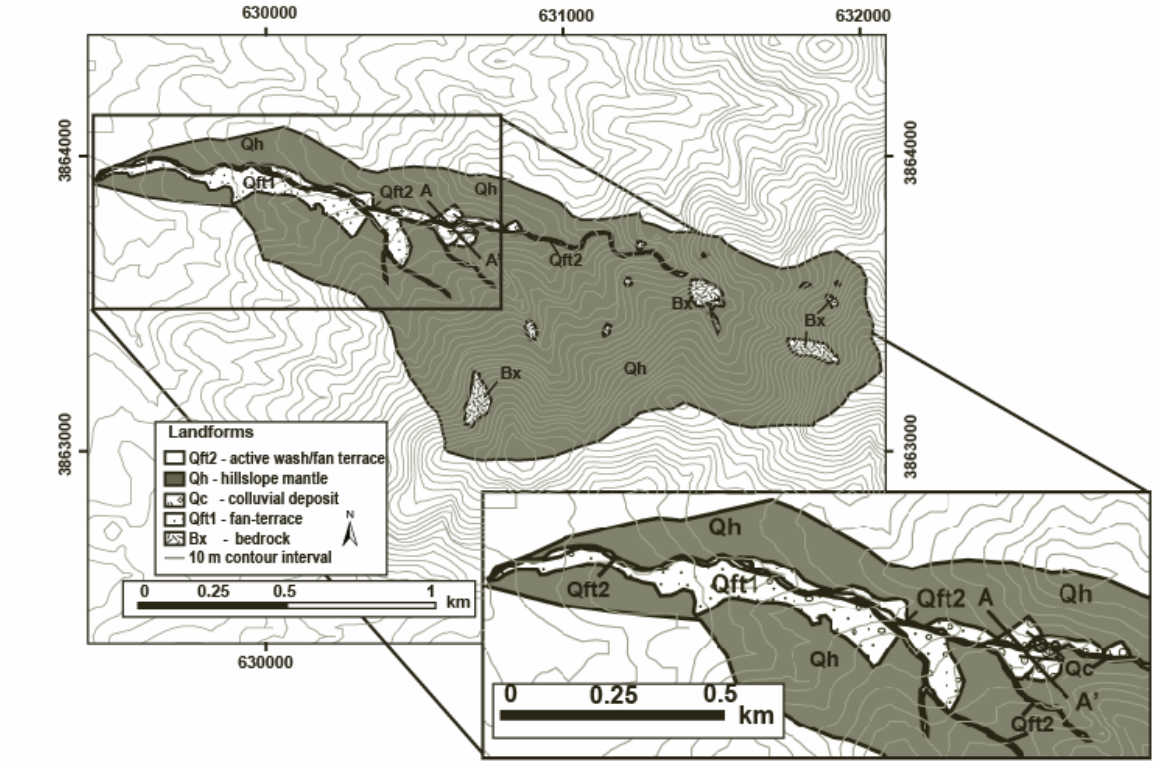

Figure 6. Geomorphic map of the Granite Basin illustrating the spatial coverage of the landforms and the topography associated with the landforms. A – A' is a cross section of the basins, shown in Figure 8.

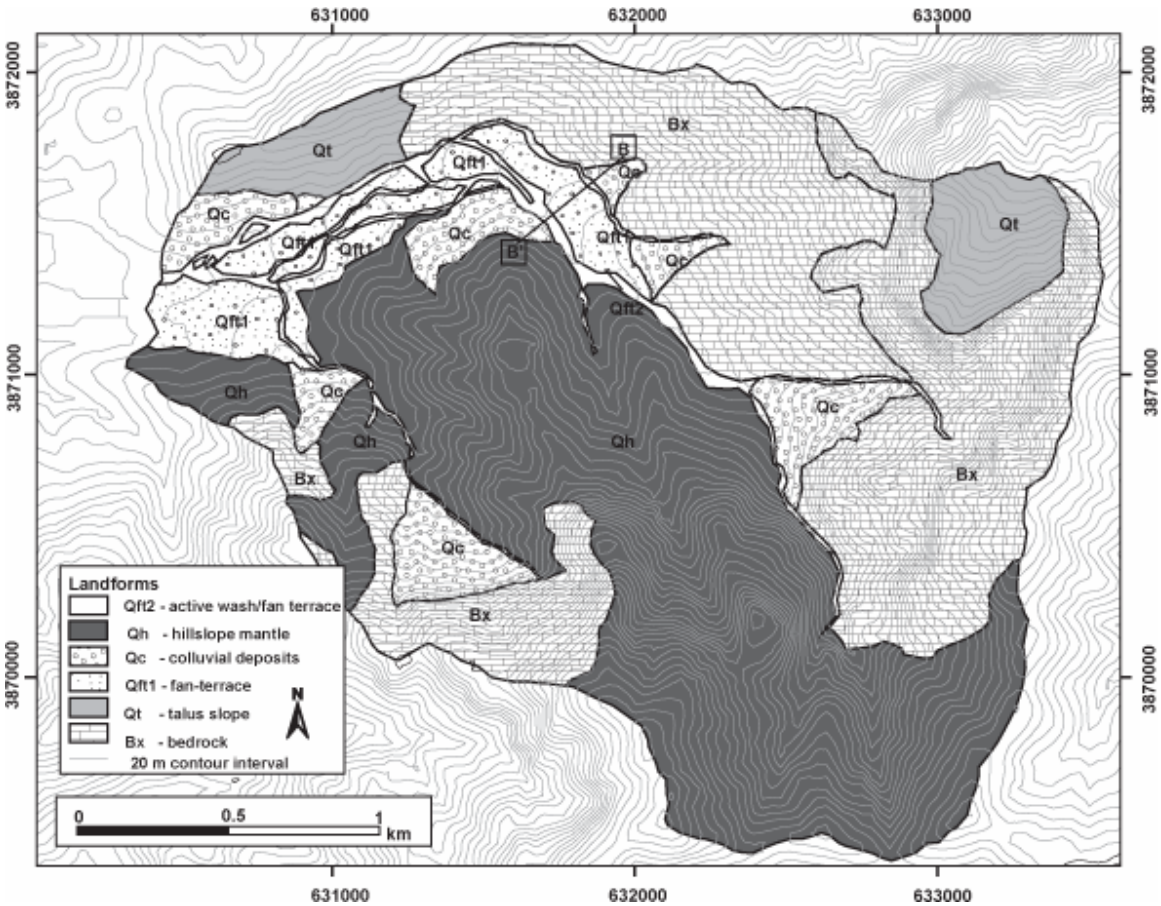

Figure 7. Geomorphic map of the Limestone Basin illustrating the spatial coverage of landforms and the topography associated with the landforms. B – B' is a cross section of the basins, shown in Figure 9.

ranging from 20°-50°, with minimal vegetative cover. Fan-terraces formed as terraces on the basin floors, but can be mapped from the basins to the piedmont where they form the alluvial fans mapped by McDonald (1994). Fan-terraces can be recognized in part by their location along the axial drainages of both basins and their low slope angle (0º - 20º). Colluvial deposits are defined by transport of sediment from the hillslopes onto the fan-terraces. Colluvial deposits form on both sides of the axial drainage and soil development on these landforms is not significantly affected by slope aspect (Table 2).

Soil profiles representative of colluvial deposits generally consist of A/AB/Bwk/Ck horizon development. In the Limestone Basin colluvial deposits tend to form below rock

Table 2. Spatial landform coverage of the Limestone Basin and Granite Basin.

Landform	Granite Basin		Limestone Basin			
	% land coverage	slope range (degrees)	% land coverage			slope range (degrees)
			Total	S-facing (weighted %)	N-facing (weighted %)	
Qft2 - drainage/youngest fan-terrace	2	0-20	3	n.d.	n.d.	0-20
Qh - hillslope soil	90	0-40	42	0	81	20-70
Qc - colluvial apron	1	0-20	7	10	7	0-30
Qft1 - fan-terrace	4	0-20	5	n.d.	n.d.	0-20
Qt - talus slope	0	n.d.	6	15	0	10-40
Bx - bedrock	3	20-40	37	76	12	30-70

scars on the south facing slope and below bedrock outcrops on the north facing slopes. Hillslope mantle soils are consistently the thinnest soils in both basins (19 ± 13 cm in the Granite Basin and 39 ± 16 cm in the Limestone Basin), composed of poorly developed soil profiles that lack a B-horizon. Hillslope mantle soils in both basins have formed on bedrock that has been intermittently exposed to the environment. Bedrock underneath the hillslope mantle soils in the Limestone Basin has dissolution weathering patterns and in the Granite Basin the bedrock below the hillslope mantle deposit is highly friable. Evidence of debris flows occurring during different time intervals were observed in both basins. The spatial coverage of the debris flows compared to the square area of the basins was minimal. Debris flows were not visible on the aerial photographs and thus were not marked on the geomorphic maps, but they are part of the sediment transport system in both basins making it important to acknowledge their presence.

Spatial coverage and slope angles of landforms calculated using ArcMap 9.1 (Table 3), were combined with soil development data and used to analyze the

relationships between sediment storage and landforms in the basins. A color-coded slope map was created for each basin. Landform outlines were placed over the slope map to identify the range of slope degrees that represented specific landforms. More than two

Table 3. Particle size distribution of sediment on landforms in both basins.

Landform	Granite Basin					Limestone Basin				
	Particle size distribution					Particle size distribution				
	Gravel %	Sand %	Silt %	Soil Thickness (cm)	# soil pits	Gravel %	Sand %	Silt %	Soil Thickness (cm)	# soil pits
	Standard deviation of ± 1 sigma					Standard deviation of ± 1 sigma				
Qft2 - drainage/youngest fan-terrace	40 ± 16	49 ± 13	11 ± 5	81	2	61 ± 10	21 ± 4	18 ± 9	61 ± 36	3
Qh - hillslope soil	51 ± 18	34 ± 13	15 ± 5	19 ± 13	12	47 ± 9	23 ± 5	31 ± 7	39 ± 16	3
Qc - colluvial apron	41 ± 7	41 ± 5	18 ± 5	94 ± 12	3	44 ± 8	29 ± 8	28 ± 8	92 ± 21	4
Qc - colluvial apron (N-facing)	46 ± 6	38 ± 5	17 ± 5	81	1	40 ± 8	30 ± 8	30 ± 9	85 ± 20	3
Qc - colluvial apron (S-facing)	39 ± 6	42 ± 5	19 ± 5	100	2	51 ± 7	27 ± 7	23 ± 11	112	1
Qft1 - fan-terrace	33 ± 9	52 ± 6	15 ± 6	83 ± 27	3	48 ± 15	31 ± 8	21 ± 9	97 ± 25	3

pixels of a representative slope degree had to be present within a landform outline for the slope degree to be considered representative of the landform. The Limestone Basin exhibited much steeper slope degrees than were present in the Granite Basin due to folding of the bedrock and differences in long-term weathering and stream incision rates between the two basins (Table 3). Due to non-uniformity of landform distribution in the Limestone Basin weighted percentages of landforms that formed on the north and south facing slopes were completed (i.e. bedrock, colluvial deposits, hillslope mantle, and talus slopes), fan-terraces were not included in this analysis because they have no significant slope aspect associated with them (Table 3).

Spatial analysis of landform coverage in the Granite Basin (Figure 6 and Table 2) identified very similar patterns of landform deposition on both sides of the axial drainage. Bedrock outcrops only covered 3% of the total area and no talus slopes were visible on the aerial photographs of the Granite Basin. Alluvial fan-terraces (Qft1 and Qft2) formed along the axial drainage and dominated the basin floor, but composed only 6% of the

total spatial area. Hillslope mantle soils were uniformly distributed throughout the Granite Basin and composed 90% of the total spatial land coverage.

Bedrock in the Limestone basin covers 37% of the total land area, dominating the south facing slope (Table 3). Talus slopes cover 6% of the total area and were only visible on the south-facing slope. Alluvial fan-terraces (Qft1 and Qft2) formed along the axial drainage and basin floor, representing 8% of the total land coverage in the basin (similar distribution to the Granite Basin). Hillslope mantle sediment compromises 42% of the total spatial coverage in the Limestone basin and 81% of the spatial coverage on the north facing hillslopes. Hillslope mantle soils are not present on the south facing slope, which is dominated by bedrock and talus slopes. On the north facing slope bedrock has eroded into ledges approximately one meter wide that dip 10º to the south. The bedrock ledges exhibit strong surficial weathering forming a very rough bedrock surface that acts as a sediment trap resulting in considerable accumulation of eolian deposition throughout the soil profiles on the north facing slopes. The steep slope angles of the south facing portion of Limestone Basin only permits a thin veneer of sediment to stabilize on the hillslopes, allowing for minimal vegetative cover which is dominated by desert barrel cacti. Variance in bedrock expression on either side of the axial drainage in the Limestone Basin resulted in non-uniform distribution of hillslope mantle soil. Distribution and location of formation of fan-terraces and colluvial deposits were very similar between the Granite and Limestone Basins, geologic expression and slope aspect did not appear to be significant factors effecting the formation of these landforms.

Dendritic stream patterns dominate the north facing slopes of both basins first order channels with a small number of secondary channels (Strahler, 1952) feed into the

axial drainage that flows west out of the basins (Figure 3). The first order and second order drainages present in the basins commonly experience brief periods of episodic flow, on the order of a few hours. During extremely wet years the axial drainage may maintain ephemeral flow during winter and early spring months.

Multiple soil pits were excavated and analyzed on the landforms in both basins. Analysis of the soil pits identified uniform soil horizon development and sediment thickness on each landform within their respective basins. Table 2 shows the whole soil particle size distribution averaged over the horizons of each landform. Figures 8 and 9 illustrate a cross-section of each basin with a soil profile figure and particle size graph representative of specific landforms within each basin.

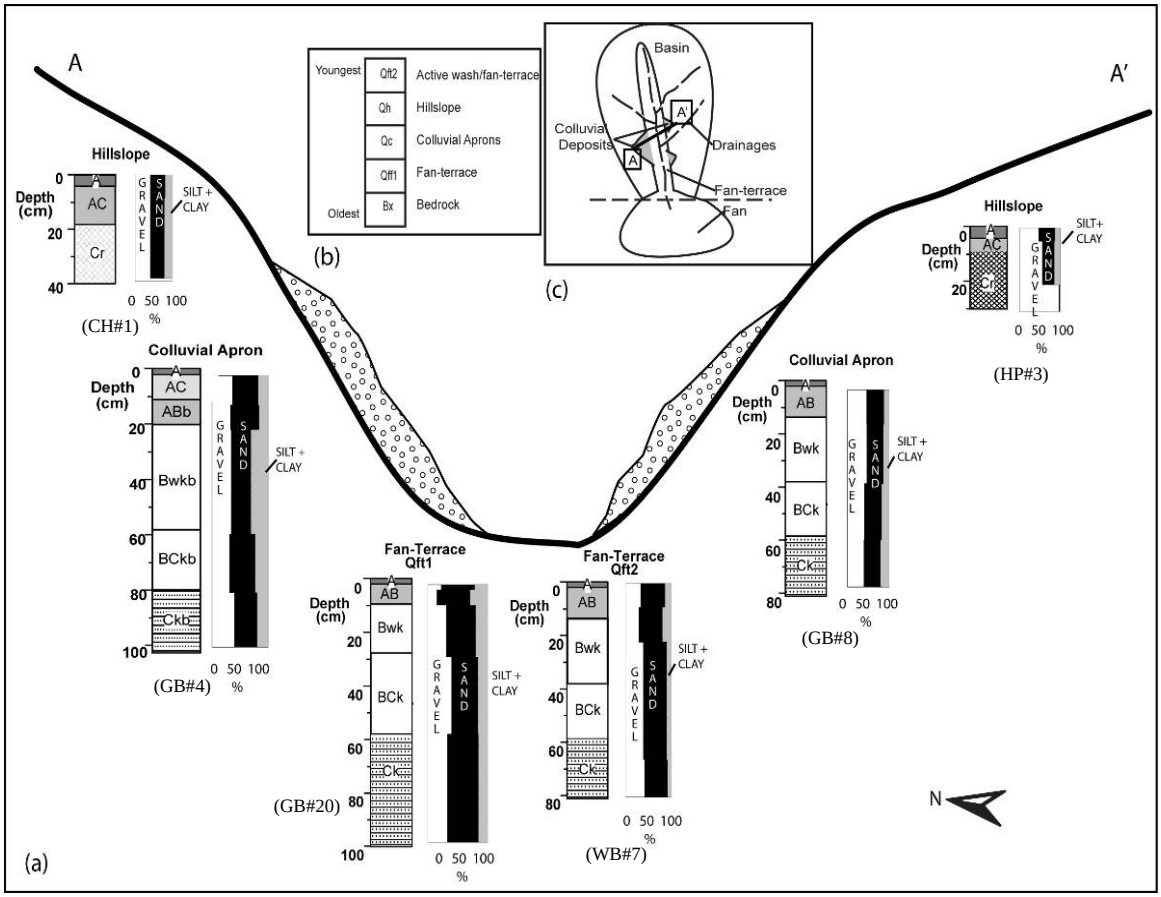

Figure 8. a) cross section illustrating the soil profiles associated with specific landforms in the Granite Basin, combined with particle size analysis correlated to the specific horizon of each soil profile b) chronology of geologic and depositional events c) schematic of landforms in the basin. (See Appendices 1, 2, and 3 for more detailed soil profile information). Location of A-A' shown in Figure 6. Patterned unit on x-section represents colluvial aprons.

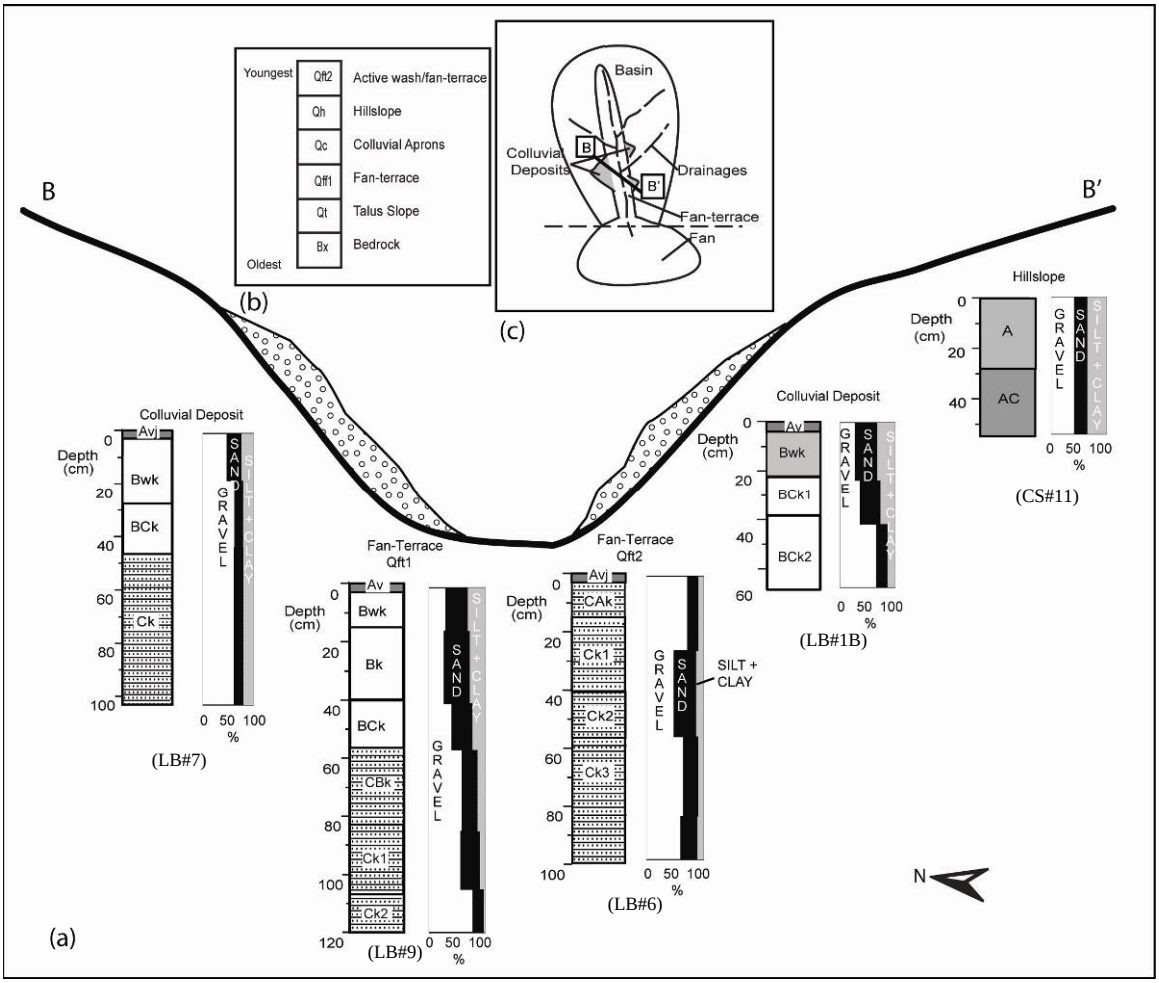

Figure 9. a) cross section illustrating the soil profiles associated with specific landforms, in the Limestone Basin combined with particle size analysis correlated to the specific horizon of each soil profile. b) chronology of geologic and depositional events c) schematic of landforms in the basin. (See Appendices 1, 2, and 3 for more detailed soil profile information). Location of B-B' shown in Figure 7. Patterned unit on x-section represents colluvial aprons.

Over 20 soil pits of varying depth (10 - 40 cm) were excavated in the hillslope mantle soil of the Granite Basin. Based on the uniformity of soil development observed in these soil pits, 11 soils were designated as representative of the hillslope mantle soils and samples were collected from each soil horizon of these pits. The hillslope mantle and Qft2 fan-terrace soil profiles both have weak soil development that lack formation of a B-horizon (Figure 8). Soils formed on the Qft1 fan-terrace and colluvial deposits in the

Granite Basin exhibit similar soil horizon sequences, A/AB/Bwk/BCk/Ck, but due to the stratigraphic position of the formations (the Qc landform was deposited on top of the Qft1 fan-terrace) it was determined that the Qft1 fan-terrace soils are slightly older than the soils formed on the colluvial deposits (Figure 8).

Table 3 shows the particle size distribution on the different landforms within each basin. In the Granite Basin the percent gravel in soils ranged from 33 ± 9% in soils formed on the Qft1 fan-terraces to 51 ± 18% in soils formed on the hillslope mantle. The Qft1 and Qft2 fan-terraces formed in the Granite Basin have similar gravel content. Debris flows contribute sediment ranging from fine-grained particles up to boulders onto the fan-terraces, thus supplying increased gravel onto the soils developed on the landforms on the basin floors. Sand distribution in the Granite Basin ranged from 34 ± 13% in the hillslope mantle soils to 52 ± 6% in the Qft1 fan-terrace deposits. Analysis of all the soil data from the Granite basin identified an overall decrease in sand with depth in soils developed on all landforms. Silt distribution ranged from 11 ± 5% on the Qft2 fan-terraces to 18 ± 5% on the colluvial deposits and does not change considerably with depth on any of the landforms.

Soil profiles described on the colluvial deposits in the Limestone Basin have a less developed B-horizon than the Qft1 fan-terrace soil profiles, but are more developed than the Qft2 soil profiles. Hillslope soils in the Limestone Basin also lack development of a B-horizon (Figure 9). Gravel, sand, and silt content did not range considerably with depth in soils formed on the colluvial aprons in the Limestone Basin.

Soil profiles in the Limestone Basin have less sand and more gravel than in the Granite Basin. Silt content of soils formed on landforms within both basins tends to be

uniform with respect to the landform on which the soil developed. Standard deviation of the average silt content of the various landforms throughout both basins was small, ranging from 5 to 6 % in the Granite Basin and 7 to 11% in the Limestone Basin, indicating constant silt accumulation on landforms over time in both basins.

4.2 XRF Analysis

XRF analysis was utilized to study the composition of soils formed on various landforms and elucidate the origin of the fine-grained particles found throughout the soil profiles in both basins. Scatter plots were developed using ratios of major oxides rather than straight percentages to avoid statistical problems based on sample size (Reheis and Kihl, 1995) (Figure 10). The chemical composition of the sand particles (2000 - 63 µm) and the bedrock in both basins are relatively dissimilar. However, more samples would be necessary for a conclusive determination of the relationship between sand particles and bedrock. XRF analysis of silt (<63 µm) samples identified very similar chemical composition of silt between the two basins, and very dissimilar chemical composition of silt samples compared to bedrock samples collected from either basin. The chemical variation between the silt and the bedrock within both basins is a strong indicator of an outside sediment source supplying fine-grained sediment into the basins.

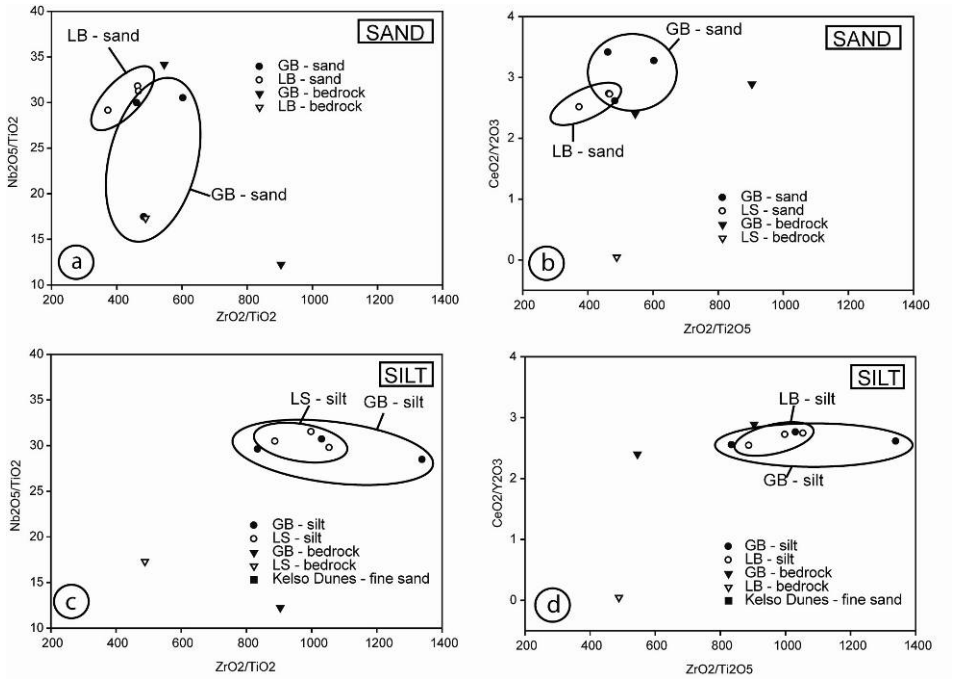

Figure 10. Note the different scales on each graph. Ratio concentrations of the ZrO2/TiO2 vs. Nb2O5/TiO2 and ZrO2/Ti2O5 vs. CeO2/Y2O3 in the silt, sand, and bedrock of the Granite Basin and Limestone Basin Mojave Desert, CA. a) Granite Basin sand is somewhat similar to bedrock within the Granite Basin, where as the Limestone Basin sand is dissimilar to the Limestone Basin bedrock, b) sand samples from both basins are very similar to each other, sand from the Limestone Basin is unlike the Limestone bedrock. c) and d) silt samples from both basins are very similar, they do not correspond to bedrock either basin.

4.3 Soil Stratigraphic correlation and age estimates

Chronology of landform depositional events in both basins (Figures 8b and 9b) were established based on the geomorphic maps, soil profile descriptions, lab data, knowledge of soil formation, and previous work completed in the Providence Mountains. Figure 11 compares profiles of soils developed on the alluvial fans that formed from the Granite Basin described by McDonald (1994) and dated using radiometric techniques (McDonald et al., 2003) to the profiles of soils formed on various landforms within the Granite Basin. Soil profiles were correlated by comparing key soil forming properties (horizon thickness, formation of silicate skins, carbonate development, ped development,

and color) between soils developed on alluvial fans and soils developed on landforms within the basins. The oldest landform in the Granite Basin is the Qft1 fan-terrace.

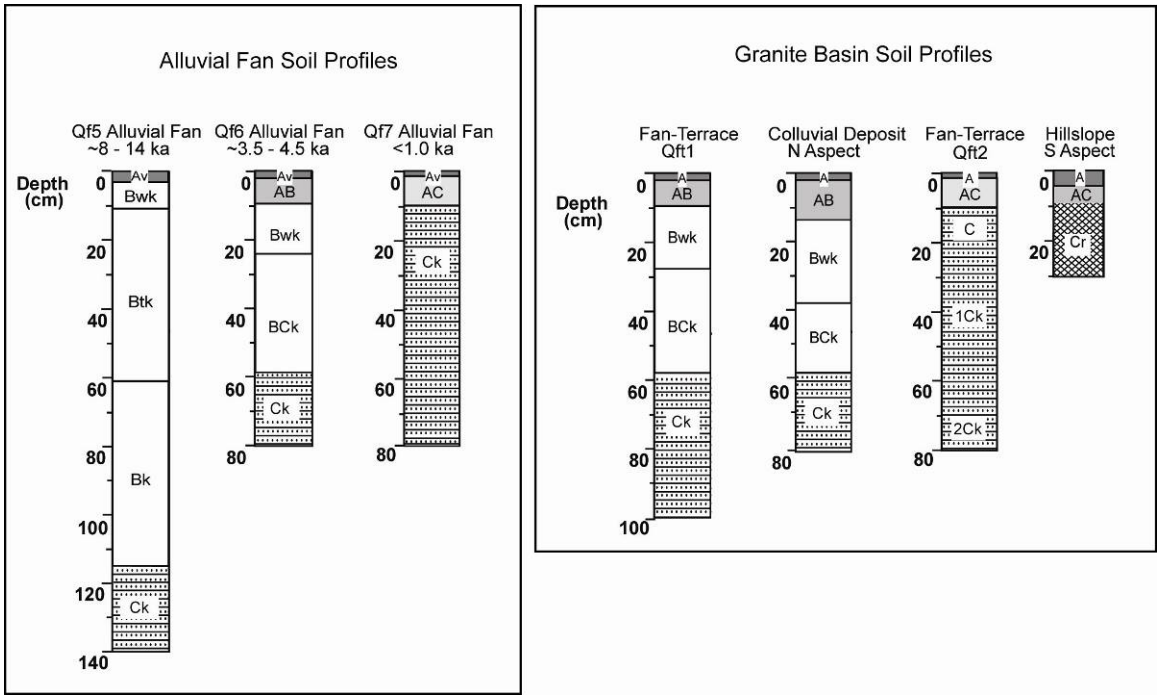

Figure 11. Comparison of the degree of soil development between soils from the alluvial fan sequence (McDonald, 1994) which formed from the Granite Basin and have been radiometrically dated to the soil profiles from landforms within the Granite Basin.

Field relationships suggest that the Qf6 fan deposit on the piedmont appears to be the Granite Basin Qft1 fan-terrace equivalent. Comparison of the Qft1 fan-terrace soil profile to the soil profiles formed on the alluvial fans identified a strong correlation between the Qft1 soils and McDonald's (1994) Qf6 alluvial fan soils. Soil horizons on the Qft1 soils in the Granite Basin have a poorly developed A horizon (1-2 cm thick), less developed than the Av horizon formed in the soil profiles on the Qf6 alluvial fans. Elevation and precipitation patterns can influence the rate of soil forming characteristics (e.g. formation of an Av horizon, carbonate development). Carbonate development and sediment thickness of B-horizons described in the Qft1 fan-terrace soils are very similar

to the soil profiles of the Qf6 alluvial fans. Soil profiles described on the Qf5 alluvial fan identified much thicker and more developed B horizons than the Qft1 fan-terrace, indicating the Qft1 fan terrace must be younger than the Qf5 fan-terrace, further supporting the correlation of the Qft1 fan-terrace and the Qf6 alluvial fan. The Qf6 alluvial fans form an extensive fan sequence on the Providence Mountain piedmont, representing a significant period of mid to late Holocene aggradation.

Using the radiometric dates associated with the Qf6 formation (McDonald, 1994; McDonald et al., 2003) the soil developed on the Qft1 fan-terrace is approximately 4 thousand years old. Degree of soil development on the Qc colluvial deposits and Qft1 fan-terrace landforms in the Granite Basin are similar, implying formation of both landforms occurred during the same general time period, indicating the Qc colluvial apron is approximately 4 thousand years old. The Qc colluvial deposit is stratigraphically positioned on top of the Qft1 fan-terrace, implying the Qc is at least slightly younger than the Qft1 fan-terrace. The Qft2 fan-terrace is inset into the Qft1 fan-terrace, indicating that it is younger than the Qft1 fan-terrace. Both the Qft2 fan-terrace and hillslope mantle soils in the Granite Basin are poorly developed. Soils developed on both landforms lack a B-horizon and have a thin AC-horizon developed atop the C-horizon, based on the weak degree of soil development, both profiles can be correlated back to McDonald's (1994) Qf7 soil profile which is also poorly developed and has a similar soil development sequence to the Qft2 and hillslope soil, implying that both the Qft2 and hillslope landforms formed <1 ka.

Using the same criteria as in the Granite Basin, the Limestone Basin soil profiles were correlated to soils developed on the alluvial fans formed from the Limestone Basin as described by McDonald (1994) (Figure 12). In the Limestone Basin, the Qft1 fan-

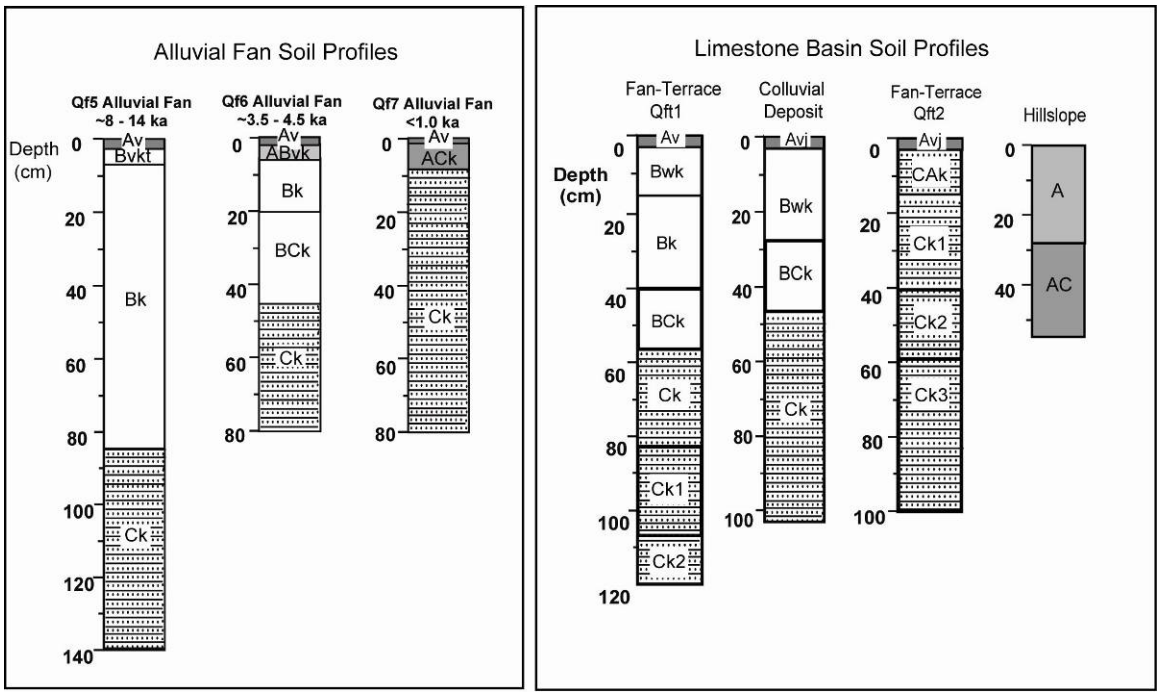

Figure 12. Comparison of the degree of soil development between soils from the alluvial fan sequence (McDonald, 1994) which formed from the Limestone Basin and have been radiometrically dated to the soil profiles from landforms within the Limestone Basin.

terrace and the Qc colluvial deposit soil profiles have similar soil development and horizon thickness to the Qf6 alluvial fan soil profile, which began forming approximately 4 ka. The Qft1 soil has multiple Ck-horizons making it appear slightly more developed than the Qf6 soil profile. Increased precipitation can amplify the rates of soil development, and the multiple Ck-horizons are likely a product of increased precipitation due to elevation in the Limestone Basin compared to the piedmont on which the alluvial fans were deposited. The multiple Ck-horizons may also be produced by increased periods of deposition, such as deposition by debris flows, occurring within the basin

environments. The Qft2 fan-terrace and Qf7 alluvial fan both lack development of a B-horizon. The Qft2 fan-terrace has multiple Ck-horizons, which makes it appear slightly more developed than the Qf7 alluvial fan formed from the Limestone Basin. The Qft2 fan-terrace soils likely formed during the same time period as the Qf7 alluvial fans, approximately <1 ka. The hillslope mantle soils have a thick but weakly developed A-horizon atop an AC-horizon, the hillslope mantle soil appears to have formed during or after the formation of the Qf7 alluvial fan, <1 ka. In both basins the colluvial apron and Qft1 fan-terrace soils have significantly stronger soil development than the hillslope mantle and Qft2 fan-terrace soils, implying that the Qft1 fan-terrace and colluvial deposits are the oldest landforms with surface expression in either basin.

5 Discussion

5.1 Soil Formation

Physical and/or chemical weathering of bedrock causes in-situ sediment production. The current Mojave Desert climate inhibits rapid physical weathering of the granite diorite bedrock found in the Granite Basin and the metamorphosed limestone bedrock that trends toward dolomite in the Limestone Basin. The extremely slow rate of physical and chemical weathering of bedrock in both basins excludes weathering processes from being the current dominant source of sediment accumulation in the basins. During cooler paleoclimates characterized by increased moisture, the bedrock in both basins may have experienced increased susceptibility to in-situ weathering processes.

There are four primary ways in which soil formation may occur on limestone bedrock: (1) residual origin, this is the insoluble residue of the parent limestone that accumulates as the limestone fraction dissolves, (2) fluvial or colluvial deposition of fine-grained materials from topographically higher terrain, (3) weathering of volcanic ash that has fallen on limestone surfaces, and (4) weathering of fine-grained eolian dust that can have very distant sources (Birkeland, 1999). In a semi-arid region, such as the Mojave Desert, the weathering rate of limestone bedrock is extremely slow and is not responsible for the appreciable amount of fine-grained sediment present in the hillslope mantle and other soils formed throughout the basin. Particle size results identified high gravel content in the soils formed on all landforms in the Limestone Basin. The source of gravels in the limestone basin is likely a result of colluvial deposition from topographic highs, physical weathering of limestone clasts, and deposition from debris flows. Weak in-situ weathering in the Granite Basin likely results in the higher sand content identified in soil profiles within the Granite Basin.

Silt is abundant in both basins with increased amounts identified in the Limestone Basin, specifically in the hillslope mantle soils. Hillslope mantle soils are twice as thick in the Limestone Basin (31 ± 7 cm) relative to the Granite Basin hillslope mantle soils (19 ± 13 cm) and contained 31 ± 7% silt in the Limestone Basin versus 15 ± 5% silt in the Granite Basin (Table 3). Based on the XRF data and knowledge of soil formation on limestone bedrock, the silt was not formed in-situ. The hillslope mantle soils are the youngest soils present in both basins, they are poorly developed, and have a sharp contact between the soil and highly weathered bedrock below. A strong eolian influence accounts for the weak soil formation, abundant fine-grained matrices, uniform soil

distribution, and sharp boundary contacts between the hillslope mantle soils and highly weathered bedrock in both basins. The above points are key indicators that a strong eolian influence supplied and continues to supply fine-grained sediment into both basins with minimal contribution of fine-grained particles from in-situ weathering.

5.2 Environmental processes controlling surficial coverage

Poorly developed hillslope soils compose the largest surficial area of either basin. After analyzing the sediment thickness, soil horizon development, and timing of events it became clear that soils developed on landforms in the basins lack the degree of soil development associated with soils formed on the Qf5 and older alluvial fans formed on the Providence Mountain piedmont. Age estimates based on correlation of radiometrically dated soils developed on the alluvial fans to soils developed in both basins found the soil cover ranged from a maximum of 4 ka to less than 1 ka, with the youngest soils developing on the hillslope mantle in both basins. The thin hillslope mantle soils (19 ± 13 cm thick in the Granite Basin and 39 ± 16 cm thick in the Limestone Basin) lack formation of a B-horizon, and have an appreciable amount of eolian derived silt and clay distributed throughout the soil profiles. The uniform soil distribution and degree of soil development on the hillslopes in both basins implies that regional excavation of soils from the hillslopes likely has occurred periodically in the geologic past, resulting in the formation of young spatially homogeneous hillslope mantle soils with uniform soil development and sediment thickness in both basins. Comparison of the Qc colluvial deposit soil profiles from both basins indicate that slope aspect does not appreciably affect soil thickness or rate of soil development in either basin. The

relatively short duration of time (<1 ka to 4 ka) that these soils have been forming may prohibit significant slope aspect differences from developing. These results support McDonald et al.'s (2003) hypothesis that formation of soil cover, followed by the transport of sediment off the hillslopes is an active Holocene processes.

Vegetation in the basins is known to have varied with paleoclimate regimes (Van Devander and Spaulding, 1979; Spaulding 1990). Vegetation currently present in the basins ranges from piñon-juniper to desert shrub, and is significantly affected by slope aspect (Spaulding, 1990). The variability of vegetation and uniformity of soils within the basins does not support the concept that vegetation, conventionally thought to control slope stability (Bull, 1991), is a key component in hillslope sediment loss in the semi-arid basins. Observations from the field, analysis of soil profiles, and conclusions from the geomorphic maps indicate that hillslope sediment is periodically eroded from hillslopes and transported onto the basin floor, resulting in silt rich colluvial deposits and young, uniformly distributed, poorly developed hillslope mantle soils. Formation of alluvial fans on the piedmont, which can be correlated to the formation of fan-terraces in the basins has occurred multiple times over the last 100 ka (McDonald, 1994; McDonald et al., 2003) indicating excavation of sediment out of the basins and transported onto the piedmont is episodic. Loss of sediment from the hillslopes is thought to be correlated to the intensity of the storm system and not impacted by the vegetative cover on the hillslopes.

Significant sediment accumulation along with more developed soils were identified on the Qft1 fan-terraces and Qc colluvial deposits in both basins. Soils developed on top of the C-horizons of both the colluvial deposits and fan-terraces range

from 48 - 93 cm thick in the Limestone Basin and 38 - 80 cm thick in the Granite Basin. In the Limestone basin, 1st and 2nd order streams had down cut along fluvial deposited fan-terraces providing cross-sectional views of the fan-terraces, which held a significant amount of sediment, up to 15 m thick and 10 m across. Using these observations it is believed that the fan-terrace deposits hold the greatest amount of sediment in both basins. This pattern of sediment distribution mimics results found by Miller et al. (2001) in a study of alluvial basins in central Nevada, where they found that the majority of present day sediment accumulation and storage occurs on valley floors where aggradation and degradation actively occur.

5.3 Timing of events: basin → fan → regional eolian activity

5.3.1 Formation of basin landforms

Based on radiometric dating techniques soils developed on the alluvial fans located on the Providence Mountain piedmont range in age from early Pleistocene to late Holocene (McDonald, 2003). Sediment that formed the alluvial fan sequence was stored in the alluvial basins prior to mobilization onto the piedmont. Soils formed prior to the Pleistocene-Holocene boundary, which were not removed from the basins, are expected to be present in areas of local soil stability within the basins, such as behind bedrock outcrops, along sheltered areas of hillslopes, and potentially along the axial drainages. The presence of pre Pleistocene-Holocene soils on specific landforms would serve as evidence of previous patterns of aggradation and degradation within the basins during periods of climate change.

The Qf5 alluvial fans are extensive and contain abundant amounts of sediment, which was stored in the basins prior to fan formation. Frequent storms with long duration and high intensity would be necessary to fully excavate all the Qf5 and older sediment from the Limestone Basin, which is 1.5 times larger than the Granite Basin. Due to the size of the Limestone Basin, it was expected that some soils present on landforms within the basin would correlate to McDonald's (1994) Qf5 alluvial fan soil profiles (~8 to 14 thousand years old). After extensive fieldwork, no Qf5 age soils were identified in either basin. The complete lack of Qf5 age soils in the basins implies two possible scenarios: (1) older soils have been reworked and re-deposited elsewhere in the basins and on the piedmont, and/or (2) older soils have been buried by more recent deposition of sediment.

Differences in bedrock expression and slope angle between the Limestone and Granite Basins were expected to result in varied distribution of landforms and development of soils on landforms. Comparison of soil profiles on multiple landforms throughout both basins identified strong uniformity between soil development and soil thicknesses on similar landforms with respect to the basins in which they formed. Similar patterns of soil development and geomorphology between the basins (i.e. soil cover thickness, weak-uniform soil development) suggest that both basins record similar late Holocene history of instability and stability. If this is true, than each basin responded to regional climatic events and increases in frequency of high intensity storms in similar ways implying that the present patterns of landform deposition and sediment accumulation in the basins is potentially the same now as during the pre-Holocene environment.

5.3.2 Chronology of fan forming events

Previous research on the timing of alluvial fan formation combined with results from this study provides insight into the geomorphic processes occurring on the alluvial fans and within basins. Based on soil profiles and extensive mapping of the fan sequences (McDonald, 1994 and McDonald et al., 2003) it is known that the Qf5 fan associated with the Granite Basin formed from frequent debris flow deposition in the mixed volcanic region of the Providence Mountains (VX in McDonald, 1994). The Qf5 alluvial fan associated with the Limestone Basin formed from ephemeral braided streams in the limestone (LS in McDonald, 1994) lithological regions (McDonald et al., 2003). Significant amounts of sediment must have been supplied from the basins to the piedmont to form such large alluvial fans, indicating significant accumulation of sediment within the basins prior to formation of the Qf5 alluvial fan. The Qf6 fan sequence formed approximately 4 ka and is also quite substantial implying a second period of significant sediment accumulation occurring within the basins after the formation of the Qf5 alluvial fan and prior to the formation of the Qf6 alluvial fan. The Qe3 sand sheet formed on top of the Qf6 alluvial fan sequence from eolian derived sediment (McDonald 1994, and McDonald, et al. 2003). Formation of the sand sheet offers insight into the influence of eolian deposition in the alluvial basins and along the Providence Mountain piedmont. Increased deposition of fine-grained particles onto the hillslopes in both basins was likely occurring during the warm dry periods in the Holocene, when pluvial lake beds were dry and sand sheets were forming on the Providence Mountain piedmont, this idea will be discussed further in Section 5.2.3.

Size and composition of the Qf6 alluvial fan sequence combined with the age of the soil formed on the Qf6 landform can be correlated to soils developed on the Qft1 fan-terrace and Qc colluvial deposits within both basins. Correlation of soil development between the basins and alluvial fans implies that sediment was deposited and soils were concomitantly developing on the Qf6 alluvial fan sequence, basin floors (Qft1 and Qft2 fan-terraces), and colluvial deposits during the same general time period, approximately 4 ka. The analogous way in which landforms were created and soils developed in both basins during the late Holocene is a strong indicator that similar patterns of soil development and formation of landforms would have occurred during the paleoclimate regimes associated with the Pleistocene-Holocene transition.

5.3.3 Regional eolian influence on sediment supply to the basins

Results from XRF analysis identified an appreciable amount of externally derived fine-grained sediment was being deposited into the basins by eolian processes. Major silt oxide ratios derived from XRF analysis of bedrock, sand, and silt from each basin provided evidence that the majority of the silt and sand accumulation in the basins is not a result of degradation of the basin bedrock but the product of an outside sediment source. Based on soil profile information, particle size data, and XRF data from the Providence Mountains it is clear that eolian deposition has a significant influence on sediment accumulation over time within the basins. XRF data identified that sand and fine-grained particles in the basin are from an external source, which means that multiple sources (i.e. playas, axial washes, alluvial fans) supplied eolian derived sediment into the basins. Basin orientation, the size and shape of the basin, and bedrock lithology were

expected to influence eolian accumulation of sediment within the basins. Results indicate spatially homogeneous deposition of fine-grained particles onto hillslopes throughout the basins, with the exception of the south facing hillslope in the Limestone Basin which has very steeply dipping bedrock that causes minimal accumulation of sediment on the hillslope. After deposition of eolian sediment onto hillslopes periodic storm events transport the hillslope sediment onto the basin floor contributing silt and fine-grained particles onto the fan-terraces and colluvial deposits.

Periods of sand sheet formation on the alluvial fans, such as the Qe3 sand sheet (McDonald et al., 2003), likely correspond to increased eolian sediment accumulation in the basins. The affect of a fluctuating climate on sediment supply to the alluvial basins has important implications on the amount and source of sediment being supplied to the basins during periods of paleoclimate change. Periods of climatic drying result in increased areas of exposed sediment which are susceptible to eolian transport (i.e. pluvial lakes). These dry periods potentially provide the basins with an increased influx of sediment to be stored until the next alluvial fan triggering event. The duration of time in which sediment builds up in the basins is potentially an important component in the size of alluvial fan formation.

5.4 Influence of climate on hillslopes

5.4.1 Hillslope processes

Based on the weak development of sediment and rapid accumulation of eolian deposition on hillslopes in both basins it appears that the climatic transition governing sediment loss on hillslopes occurred periodically throughout the Holocene. The

precipitation events must have been strong enough to mobilize hillslope sediment and deposit it on landforms along the basin floor, but not so intense as to cause mobilization of sediment out of the basins and onto the piedmont. Strong evidence for this process is found in the soils that formed on the colluvial deposits directly below bedrock scars on the south facing slopes of the Limestone Basin. The hillslopes above the colluvial deposits are primarily bedrock and from a few hundred yards away the colluvial deposits appear to be formed from rock slides and unlikely to contain much sediment. Soil pits excavated in the colluvial deposits tell a different story. Colluvial deposits maintain a uniform amount of fine-grained particles throughout the soil profiles indicating contributions of fine-grained particles from the hillslopes onto the colluvial deposits over time (Figures 8 and 9).

Previous geomorphic and paleobotanical studies (Spaulding, 1990; Van Devender, 1979) have shown that the early Holocene was marked by increased summer monsoon activity resulting in enhanced mobilization of hillslope sediments (Wells and McFadden, 1987; Bull, 1991; Harvey and Wells, 1994; McDonald, 1994; McDonald and McFadden, 1994; Reheis et al., 1996; Harvey et al., 1999; McDonald et al., 2003). The young soils developed on the landforms in the alluvial basins imply at least a second massive mobilization of hillslope sediment occurred sometime after the early Holocene and likely around the beginning of the late Holocene. This mobilization possibly transported and reworked sediment, while also burying mid-Holocene age soils.

5.4.2 Transport versus weathering limited hillslopes and the influence of bedrock lithology

Bull (1991) proposed that bedrock lithology is one of the main driving factors in geomorphic hillslope processes. Bull (1991) stated that hillslopes underlain by hard, not easily weathered bedrock undergo minor changes in geomorphic processes as a result of climate change, where as soft bedrock, which is susceptible to weathering is significantly affected by climate change. According to Bull's model, runoff can increase and sediment supply may decrease creating a weathering limited slope. If the bedrock is eroded, thinning of soils could permit increased quantities of water to percolate through the system, increasing the rate of weathering, and creating a transport limited slope. The Limestone Basin is not highly susceptible to weathering, where as the Granite Basin is relatively more susceptible to weathering and thus offers an excellent site to test Bull's hypothesis. Both basins have similar suites of landforms, similar degrees of soil development, and have experienced significant accumulation of eolian derived sediment throughout time. During periods of increased precipitation the sediment is mobilized from the hillslopes and reworked forming geomorphic landforms, such as colluvial deposits and fan-terraces, the same depositional patterns occur in both basins. Results indicate that regional climate change results in uniform development of geomorphic landforms in both basins, indicating that the underlying bedrock type has a less critical role in formation of geomorphic features during periods of climate change than Bull (1991) hypothesized.

5.4.3 Current weather patterns and their effects in the Mojave Desert

The minimal soil accumulation on hillslopes in both basins (19 ± 13 cm thick in the Granite Basin, and 39 ± 16 cm thick in the Limestone Basin) during the late Holocene does not appear to be caused by insufficient rates of soil development in the Holocene compared to the Pleistocene as proposed by Bull (1991). Steep slope angles prohibiting significant accumulation of sediment on hillslopes combined with the rate of sediment accumulation related to paleoclimate wetting and drying periods, and precipitation patterns, appear to be the main components effecting sediment loss off hillslopes in semi-arid basins. Colluvial apron soils with appreciable amounts of fine grained particles developed at the toe of hillslopes. Soils developed on colluvial deposits possibly formed by periodic excavation of hillslope sediment from the hillslopes and onto the colluvial aprons. After sediment was stripped off the hillslopes, eolian transport actively began re-depositing sediment on to the basin hillslopes and the process continued.

Evidence of older debris flows, were observed in both basins. For debris flows to form there must be abundant fine-grained sediment on a relatively steep hillslope combined with abundant moisture (Ritter et al., 2002). The fine-grained matrix in debris flows is capable of mobilizing large rocks to boulders. The abundant moisture necessary for formation of debris flows commonly comes as intense rainfall events or rapid snowmelt. Intense precipitation events have already been discussed as a key component in basin processes and likely also triggers debris flows in the basins. Sediment is transported from the hillslopes and deposited onto the basin floor where it is stored until it is re-deposited onto the piedmont. Transport processes controlling mobilization of sediment out of the basins onto the piedmont are most likely influenced by precipitation

events that are strong enough to re-work fan-terrace deposits on the basin floor and re-deposit them on the piedmont.

Observations of storm events during the winter of 2004-2005 offered insight into the effects of intense rainstorms in the Providence Mountains and the erosive power of precipitation events on hillslopes. The Mitchell Caverns weather station located at an elevation 600 m lower than the basin floor and only a few kms N of the basins recorded 217 mm of precipitation between December 28, 2004 and January 10, 2005. The Granite Mountains just a few kms SW of the Providence Mountains and at a slightly higher elevation than both basins experienced 11 days of rain during this time period, no total precipitation measurements were recorded, but in one day 152 mm of precipitation was measured in the Granite Mountains (Jim Andre, personal communication 2005). Field observations conducted in the Granite Basin on January 11 and 12, 2005 found that although significant rain had fallen over the previous 11 days there were no signs of recent mobilization of sediment off the hillslopes. Overland flow was observed indicating soil was saturated. Road cuts, which had become the low points in the topography, acted as channels for water movement resulting in substantial sediment loss. Lower elevation, 2nd order basin drainages experienced significant incision, (generally about 1-2 m). The increased precipitation did not result in significant erosion of sediment off hillslopes.

The basins are currently experiencing a period of more semi-arid conditions. Hillslopes in both basins maintain only weak vegetation, compared to the vegetative cover that is believed to have been present during the moist periods of the late Pleistocene and early Holocene (Spaulding, 1990). However, no evidence of sediment

loss was identified after the 2004-2005 precipitation events, which have a recurrence interval estimated to be 100 years (Enzel and Wells, 1997). The lack of observable erosion on the semi-arid hillslopes in both basins implies that vegetation does not strongly control erosive processes in the semi-arid alluvial basins of the Mojave Desert. The observations further support McDonald et al.'s (2003) hypothesis that in semi-arid regions changes in vegetation alone are not significant enough to be the primary reason sediment is lost off hillslopes. Observations and results of sediment stability on hillslopes discussed in Chapter II led, in part, to the research discussed in Chapter III.

5.5 Conceptual model of basin processes

Based on the extensive research completed in the Providence Mountains a conceptual model of the processes which affect production, storage, and transport of sediment in semi-arid basins was developed. The model begins with a basin that contains minimal soil cover across most of the hillslopes. Eolian sediment from local and regional sources, such as, playas, axial washes, and alluvial surfaces are deposited on the basin hillslopes, while small amounts of fine to coarse grained sediment are contributed by chemical and/or physical weathering of the bedrock. The hillslopes begin to develop a soil cover and vegetative cover likely increases. Storms move over the basin for hundreds of years without major hillslope soil loss. Periodically, a series of storms of significant duration and of a high intensity sits over the basin and excavates the hillslope soils, depositing eolian derived sediment on to the valley floor and forming a fan-terrace. Smaller storm events occur after the major storm events and mobilize any sediment left on the hillslopes, forming colluvial deposits along the toe of the hillslopes on top of the

fan-terraces. Exposed bedrock on the hillslopes, which has been weakened by weathering events and is susceptible to debris flow and rockslides, also contributes sediment on to the colluvial deposits. Soil begins to develop on the landforms where as eolian sediment is synchronously deposited and stored on the hillslopes, beginning the pattern anew. This pattern of sediment accumulation and mobilization occurs continually throughout time. The quantity of eolian sediment contributed to the basins combined with the total basin area likely affects the size of landforms formed from hillslope depositional events.

Uniformity of deposition, storage, and transport of sediment occurring in the two basins implies that the conceptual model can be applied to basins with diverse lithologies and of different square areas and slope angles. Presumably, larger basins would provide an increased area for older soils to be preserved on landforms. Applying this study to a larger basin with older soils would help establish patterns of soil deposition during periods of climate change. This would aid in evaluating the conceptual model of patterns of sediment deposition during varying climatic regimes.

6. Summary

Alluvial fans have been studied in a variety of piedmont settings, but few studies have been completed on the soil-geomorphic processes that occur within mountain drainage basins and that in turn govern the formation of alluvial fans, such as, sediment production, soil stability, and mobilization of sediment out of the basins. Previous research has focused on the relationship between alluvial fan formation and related

periods of paleoclimate transition, when plants and soil are stripped from slopes during the transition from a wet to dry climate.

Recently, the scientific community has been focusing more attention on sediment storage and slope stability processes on hillslopes (McFadden et al., 2005; Miller et al., 2001). The research presented in this paper takes hillslope studies a step further by examining production, storage, and mobilization of sediment in semi-arid basins and identifying the relationship between soil stability, sediment yield, and aggradation of alluvial fan sequences in semi-arid basins. The extensive fieldwork component of this research offers unique observations and field data to better elucidate these processes.

Mapping of soil thicknesses on the hillslopes, colluvial deposits, and fan-terraces in both basins identified sediment thickness ranging from 19 ± 13 cm on the hillslopes to 94 ± 12 cm on the colluvial deposits in the Granite Basin and in the Limestone Basin soil thickness ranged from 39 ± 16 cm on the hillslope soils to 97 ± 25 cm on the Qft2 fan-terraces. Ages of soils developed on the landforms within the basins were determined by correlating soil profiles from landforms in the basin to soil profiles of the alluvial fans, which have been radiometrically dated. Soils in the basins had very weak soil development, implying relatively young soils all forming within the late Holocene. Degree of soil development on geomorphic landforms within the basins ranged from hillslope soils <1 ka that lacked development of a B horizon to more developed soils such as the colluvial deposit and fan-terrace soils that had multiple weakly developed B-horizons and were ~4 ka. Similar patterns of formation of landforms and soil development on the landforms in both basins imply that periods of climate change affected sediment storage and transport processes analogously within the two basins. The

lack of soils older than 4 ka in either basin implies at least one period of extensive stripping of sediment off the hillslopes occurred after the Pleistocene-Holocene transition.

7. Conclusions

Interpretations of alluvial records from the Soda Mountains (The Zzyzx) fan formation and corresponding hillslopes have very similar characteristics to the Providence Mountains basins, modern day precipitation events seem to have similar effects on both fan systems. In 1988 Harvey and Wells (1994) observed that when a storm with a recurrence time in excess of 20 years hit Zzyzx during a summer monsoon event, serious damage occurred on the roads and other infrastructure. Alluvial processes caused significant geomorphic changes on the Zzyzx fans but no evidence of any geomorphic changes by mass movement processes were observed on the hillslopes. Observations from the Providence Mountains during the winter 2004-2005 and Zzyzx indicate that large storm events (low intensity – long duration) are not likely to produce significant slope erosion.

Thickness of the hillslope soils in both basins (19 ± 13 cm in the Granite Basin, 39 ± 16 cm in the Limestone Basin) compared to the soil thickness of other landforms in the basins (83 ± 27 cm and 97 ± 25 cm on the Qft1 fan-terraces in the Granite Basin and Limestone Basin) indicates that the majority of the sediment is not stored on the hillslopes even during periods of relative climate stability. Rather, sediment is removed from hillslopes in episodes of mass sediment movement, such as debris flows, landslides, overland flow, and down slope deposition. Increased frequency of high intensity storms

amplifies the potential number of precipitation events that are large enough to strip hillslopes of sediment and re-deposit the sediment onto the fan-terraces. Based on sediment thicknesses and total spatial area the greatest sediment storage within the alluvial basins is likely to occur on the alluvial fan-terraces formed on the basin floor. Miller et al. (2001) came to a similar conclusion after studying fan-terrace environments in the Great Basin region of central Nevada.

Extensive fieldwork completed as part of this research has aided in addressing many questions put forth by the scientific community and assisted in testing hypothesis based on general observations or models, but lacking in adequate field data. The appreciable amount of eolian sediment present in the semi-arid basins is evidence of the significant impact eolian influences have on soil formation and soil development of hillslope mantle soils on an area over time. Eolian sediment in the basin also raises important questions regarding the origin of the eolian contribution into the basins. Variances in the grain size combined with the large quantities of the eolian derived sediment in the basins indicate that the sediment is not solely supplied by the drying of pluvial lake beds associated with Lake Mojave.

Soils older than late Holocene were not identified in either basin. The presence of young soils across all landforms indicates major excavation of basin sediment resulting in loss or reworking of older soils within the basin. Older soils which were not reworked appear to have been covered by younger soils and were not located in either basin. Patterns of landform development and soil formation were similar in both basins indicating that although the basins had varied lithologic expression, slope angle, and total area, paleoclimate events affected both basins in analogous ways. Similar patterns of

landform development and quantities of sediment accumulation in both basins do not support Bull's (1991) hypothesis of differing erosion rates of bedrock resulting in varied sediment accumulation and landform development in lithologically different basins.

Applying results from this study to larger basins in different regions would provide the fieldwork necessary to test how findings from this work can be applied to other regions. Trenching fan-terraces to locate buried soils would offer insight the depositional history of fan-terraces in basins. Infiltration and rainfall simulation studies on various surfaces would provide data on the timing of runoff on various soil surfaces and potentially when and where rill formation occurs. Establishing the origin of the fine-grained particles in both basins could lead to further studies on the various sources of eolian sediment coming into the basin (i.e. playa, axial washes etc.) and a greater understanding of the relationship between climate fluctuations, increases in eolian sediment, and alluvial fan size.

Chapter III - Effect of Fire on Hillslope sediment loss in the semi-arid Mojave Desert

1. Introduction

Loss of vegetation is commonly thought to be a catalyst of hillslope erosion resulting in loss of sediment off hillslopes and formation of erosional features such as rills and eroded soils (Ahlgren and Ahlgren, 1960; Helvey, 1980; Soler and Sala, 1992). Recent research completed in Boreal and Chaparral forests however, have found evidence that fire may not always be associated with mobilization of sediment from hillslopes (Germanoski and Miller, 1995; Carcaillet et al. 2006; Rulli et al., 2006). Because it is commonly believed that loss of vegetation after a fire causes significant erosion of hillslope sediment the feedback relationship between vegetation and hillslopes is potentially over emphasized in semi-arid to arid ecosystems (Ahlgren and Ahlgren, 1960; Helvey, 1980; Soler and Sala, 1992). The research presented in this chapter focuses on elucidating erosional processes associated with recent fire on semi-arid hillsides in the Mojave Desert. Recent work completed in blackbrush (*Coleogyne ramosissima*) dominated areas of the Mojave Desert found that blackbrush is highly susceptible to fire (Brooks, et al., 2005). The volatility of blackbrush combined with the increased invasion of cheatgrass into blackbrush regions significantly increases the fire hazard in many areas within the Mojave National Preserve (Brooks, et al., 2005). Results from Chapter III increase the understanding of hillslope stability discussed in Chapter II, while providing further understanding of the control of vegetation on sediment loss of off hillslopes and in turn the potential affect of fire on hillslope erosion rates.

In late June 2005, a fire in the Mojave National Preserve burned over 284 km^2, completely destroying a large amount of the desert grasses, shrubs, and trees. The burned area provides an excellent location for a field based study of natural pre- and post-fire processes occurring on hillslopes in the semi-arid Mojave Desert. This study focuses on understanding the pre- and post-fire processes that affected the burned hillslopes in two different ecotones one year after the fire.

Hypotheses are proposed regarding the role of fire on hillslope stability: (1) fire in semi-arid regions does not have a significant effect on soil properties, such as, particle size distribution and infiltration rates, and (2) loss of vegetation by fire does not necessarily result in increased rill formation on hillslopes and/or sediment loss from hillslopes in semi-arid regions. These hypotheses test the traditional belief that fire may be the primary catalyst for hillslope erosion in semi-arid regions.

2. Background

2.1 Site location

This study was completed in the Mid Hills region of the Mojave National Preserve located in southern California (Figure 13). The field area is on the border separating piñon-juniper dominated hillslopes and yucca-blackbrush covered hillslopes. The two ecotones provided comparison between burned and unburned hillslopes with appreciably different vegetation coverage, all within a 3.8 x 0.4 km^2 area. Two pairs of burned and unburned hillslopes were chosen within 0.5 km of each other. Each field site is roughly 30 x 30 m. The small field sites allowed for a detailed study of various aspects of pre- and post-fire hillslope processes. The field sites consisted of an unburned piñon-

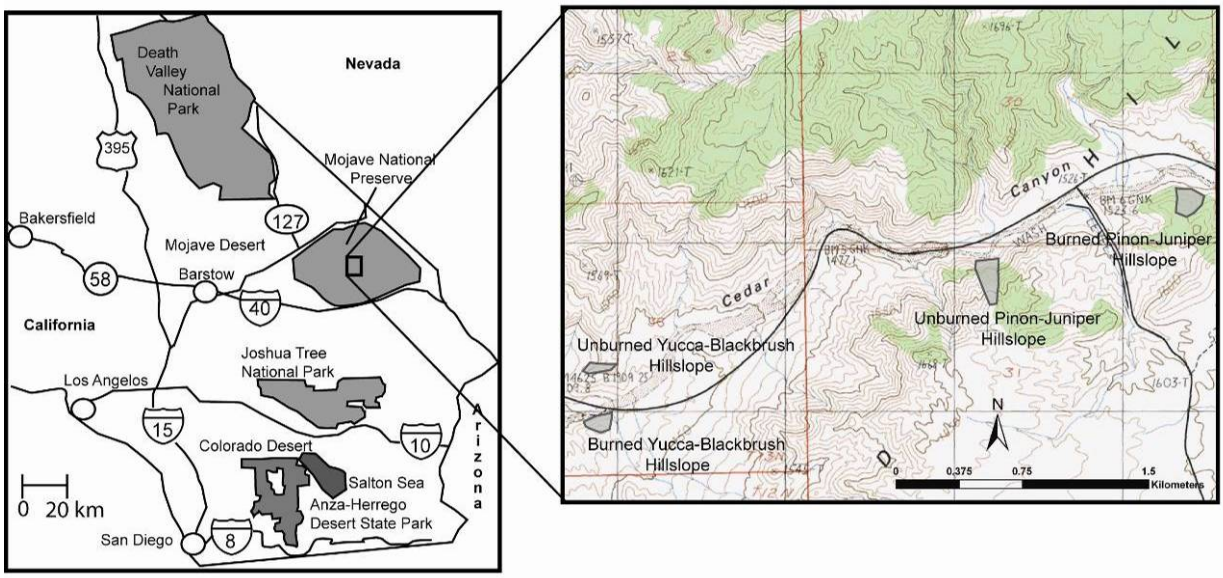

Figure 13. Location map of field sites.

juniper covered, a burned piñon-juniper covered hillslope, an unburned yucca-blackbrush covered hillslope and a burned yucca-blackbrush covered hillslope (Table 4). Slope aspect, slope angle, bedrock, and pre-fire vegetative cover are similar for each pair of burned and unburned sites. The piñon-juniper dominated hillslopes have visibly less low growing shrubs and overall vegetative cover than the hillslopes dominated by yucca-blackbrush vegetation.

Table 4. List of the four field sites.

Sites
Piñon-Juniper Hillslope - Unburned
Piñon-Juniper Hillslope - Burned
Yucca-Blackbrush Hillslope - Burned
Yucca-Blackbrush Hillslope - Unburned

The dominant (mesocratic) bedrock in the area is coarse grained granite that is very susceptible to grussification and tends to be sapprolitic at depths of 30 cm below the ground surface. The surface cover of the burned yucca-blackbrush hillslope was dominated by gruss and fine-grained angular clasts (<5 cm^2) of what appeared to be quartzite or fine grained dike/vein rock fragments. Sparse outcrops less than 2 m^2 of the quartzite like rock were observed on top of the easily grussified granitic outcrops. The easily weathered granitic bedrock results in rapid accumulation of sediment on hillslopes by physical weathering, creating transport limited slopes on all four field sites.

Elevation of the field sites ranges from approximately 1500 – 1550 m for the (yucca-black brush hillslopes) to 1550 - 1600 m (piñon-juniper field hillslopes). Climate data has been collected since 1958 at the Mitchell Cavern Weather Station, located approximately 15 miles south of the field area. The majority of precipitation falls between January and March in the form of frontal storms and between July and September as convective storms, resulting in approximately 30 cm of annual precipitation. The mean annual temperature in the region is 23° C, with the highest temperatures occurring in July and August and the lowest temperatures occurring December through January. The Mid Hills region generally has temperatures 2-5 ° C cooler than the Providence Mountain Basins (Chapter II).

2.2 Fire history

Lightning strikes ignited a fire in June 2005 that burned over 70,000 acres of the Mojave National Preserve. The fire burned through multiple vegetation zones, including hillslopes covered in Mojave Desert scrub, yucca, and joshua trees and hillslopes

dominated by piñon and juniper trees. The intensity of the fire appeared to have been highly variable on the hillslopes. In some areas the burn was intense enough to completely destroy all standard vegetation, resulting in ash circles on the ground surrounding the roots of the disseminated plants. In other areas, one year after the fire, there was no observable surface evidence of the burn and the trees appeared to have been only slightly charred, but not killed by the fire. Based on evidence from aerial photographs and a short-recorded fire history in the Mojave Preserve it is clear that fires have occurred in the past although the frequency of fire events is unknown (Westerling et al., 2003; Brooks, et al., 2005). Evidence of a previous burn was identified in some of the soil profiles on the unburned piñon-juniper hillslope, but no record of this fire exists, implying it was pre-1960.

2.3 Previous research on hillslope erosion

Studies completed on hillslope erosion after a fire have been limited due to the inherent difficulty of setting up these studies under natural conditions. Many studies of hillslope erosion have been completed by field and lab experiments incorporating rain fall simulators and looking at the results of sheet flow over a relatively small area (Abrahams et al., 1995; Bochet et al., 2006; Shakesby and Doerr, 2006). Minimal studies have been completed on rill formation on hillslopes in a natural environment. Previous studies have often focused on the use aerial photographs to look at the spatial coverage of pre- and post-fire rills (Moody and Martin, 2001). Limited research on the erosional effects of fire on hillslopes has been completed in arid to semi-arid natural setting such as the Mojave Desert. The burned and unburned slopes in the Mid Hills region provide a study area

where observations can be made on the relative effect rainfall has over an entire hillslope and the erosional processes associated with the two different vegetative regimes.

Germanoski and Miller (1995) completed an erosional study eleven years after a wildfire burned a juniper and sage brush dominated environment in Crow Canyon, located in Eastern Nevada. The objective of their research was to quantify the amount of erosion and deposition that occurred on the hillslopes eleven years after the hillslopes were burned. Multiple transects were completed and measurements of the change in surface elevation on all hillslopes was done using the lowest measurable burn line etched into standing tree trunks as a baseline. They also measured deposition and/or erosion of every tree located within 10 m of either side of the transects. Minimal net change in surface elevation on the burned hillslopes was identified from measurements of sediment to burn etch lines on tress. Results indicated nominal amounts of sediment (+/- 1 cm) were locally eroded and re-deposited on the hillslopes, although sediment was not mobilized from the hillslopes. Further work in the basins by Germanoski and Miller (1995) found that the toe of the hillslopes appeared to remain stable during these erosional and depositional time periods, and that very little sediment was removed from the hillslopes. Their work went on to look at the axial drainages and fans which had post-fire deposition and is where they identified the most significant post-fire geomorphic responses.

A recent study in a boreal forest in eastern Canada examined lake sediment in seven lakes to identify periods of post-fire sediment mobilization (Carcaillet et al., 2006). The research identified a strong fire history in the region but the data did not find significant post-fire sediment loss from the surrounding hillslopes into the lakes. This

work provides an excellent example of minimal post-fire hillslope erosion in a moist environment. Carcaillet et al. (2006) concluded that fire does not necessarily trigger erosion in cold temperate or boreal lake catchments, instead the fire and erosional processes appear independent of one another. They are careful to point out that their conclusions do not imply the possibility that one single fire event can cause significant erosion if fire intensity and precipitation events are “ideal”.

Significant work has been done looking at rills on uncultivated vs. cultivated slopes. A rainfall simulator was used to study rill formation on an uncultivated, but cleared forest soil in the Loess Plateau Region of China. The field site consisted of plots 5 x 1.5 m wide with a slope of 28°. Rainfall was applied at a rate of 15cm/hr, yet rills did not form (Yang et al., 2006). Instead, the researchers had to manually create rills (<10 cm deep) at the toe slope of the plot with a spade. Once the rills were created they began to propagate upslope. At the end of the run the rills had similar widths between the cultivated and uncultivated soils, but the man-made rills on the slope were half as deep (8.8 cm) as the rills formed on the cultivated slopes (16.5 cm). Yang et al. (2006) also used Be-7 and Cs-137 to better evaluate the sediment contribution of sheet erosion compared to rill erosion, using relative amounts of radio nuclides (Bq/kg) in eroded vs. undisturbed soils to establish the mass of sediment mobilized.

Infiltrometer measurements have been used on hillslopes to identify rates of infiltration with regard to various slope aspect, seasonal differences, and slope angle (Casanova et al. 2000; Cereda, 1997; Dunne et al. 1991). Most infiltration experiments have been completed on areas where there has been some anthropogenic alteration vs. areas that have been relatively undisturbed. Initial research using infiltrometers has identified

significant differences in seasonal infiltration rates and infiltration rates on slopes with varied slope aspect. Casanova et al. (2000) found that steeper slopes had faster infiltration rates and Cereda (1997) identified seasonal differences with infiltration rates on hillslopes in semi-arid regions.

2.4 Cesium-137 dating as a tool to measure sedimentation and erosion

Cesium-137 dating is a radiometric dating technique that relies on measuring the concentration of Cs-137 in sediment. The presence of Cs-137 is the result of nuclear fallout, primarily from nuclear weapons testing during the mid 1950's and early 1960's. Cs-137 has a half life of 30.3 years and does not form naturally in the environment. Cs-137 rapidly adsorbs on soils and in sediment due to direct deposition from the atmosphere, wash-off from vegetation, bioturbation, redeposition of eroded soil particles and deposition from water on floodplains and coastal regions (Ritchie and McHenry, 1990). Cs-137 was first commonly used in agriculture and silviculture studies to better understand erosion rates associated with these practices. Cs-137 dating has become increasingly useful in the study of sedimentation rates of channels and debris flows (Griffith et al., 2006; Yang, et al., 2006). A recent study by the Griffith et al. (2006) used Cs-137 to quantify erosion rates of small drainages in the Mojave Desert and Yang et al. (2006) used Cs-137 combined with Be-7 to study sediment contributions from sheet vs. rill erosion.

Depth to Cs-137 concentration profiles can be used to identify areas of localized sediment movement. Cs-137 tends to bind to fine grained silt and clay particles and only dates sediment less than approximately 50 years old. Cs-137 can be redistributed

throughout a soil profile by bioturbation and other erosional and depositional events. Cs-137 spikes within a profile indicate that the sediment was at or near the surface when fallout peaked in 1963. The max Cs-137 concentration resulting from global fallout measured in the general region was 480 Bq/m^2 measured in Los Angeles, CA in 1963 (Griffith et al., 2006; adapted from Hartley, 1994). Griffith et al. (2006) found the 1963 fallout in the Mojave Desert to be approximately 2.5 pCi/g, in samples taken from active washes.

3. Methodology

Two sets of burned and unburned hillslopes were chosen for this study. Sites were paired by identifying one unburned slope and an analogous burned slope with similar underlying bedrock, slope aspect, slope angle and pre-fire vegetative cover. Site locations were chosen within two different vegetative ecotones: piñon-juniper dominated hillslopes and yucca-blackbrush dominated hillslopes. Detailed observations of the vegetation and surface topography of each site were documented along with bedrock type and slope aspect. Topographic maps of the area were used to calculate the average slope at each site.

Three canopy-interspace areas were chosen on each hillslope (piñon or yucca depending on the vegetation of the hillslope). Soil pits were excavated to the AC/Cr horizon (~30 – 50 cm) within approximately 1 m of the upslope, down slope, and side slope of each tree and an interspace soil pit was excavated within 3–5 m of the tree in an area of sparse or no vegetation (Figure 14). A total of 12 soil pits were excavated on each hillslope, except for the unburned piñon-juniper hillslope which had an additional

interspace soil pit excavated, while searching for evidence of an old fire. Soil pits on the burned hillslopes were excavated below vegetation that had evidence of the most severe burns. On the burned piñon-juniper hillslope vegetation with blackened ash circles

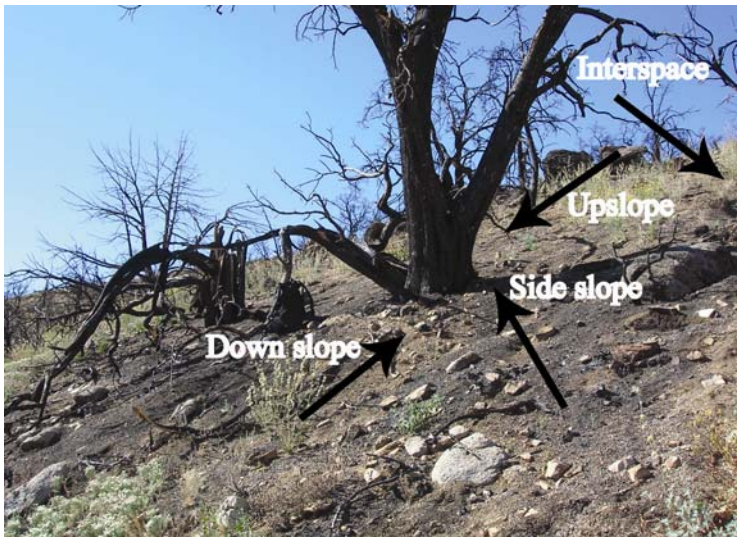

Figure 14. General soil pit locations shown on the burned piñon-juniper hillslope. Arrows point to the general location of the soil pits in regard to the tree.

around the base of the trees were deemed indicative of a severe burn. Severe burn areas on the yucca-blackbrush hillslope were identified as locations where vegetation had been completely destroyed, leaving only the base of the plant stalk present above the soil line.

Bulk soil samples were collected from each soil horizon and soil profiles were described for all soil pits excavated on each of the four field sites using standard soil describing methods (Birkeland, 1999; Soil Survey Staff, 2003). Samples from the top three horizons, which have the most affect on infiltration rates and are most susceptible to alteration by fire, were sieved to <2mm and analyzed for fine organic matter using the loss on ignition (LOI) method (Storer, 1984 and Powell, 1989). Litter, such as pine needles and piñon-nuts are not measured when using LOI. LOI is a crude method for

measuring fine organic matter. Samples were collected from the two A-horizons directly below the coarse grained surface horizon (the A1- and A2-horizons), each sample was sieved to <2mm and analyzed for particle size using a laser light scattering method (Gee and Or, 2002). Due to the coarse grained nature of the top horizon (C/O-horizon) it was sieved to <2mm and only percent gravel was calculated.

Transects were completed perpendicular to each hillslope across the down slope, mid-slope, and upper sections of the hillslopes in areas where rills or other disturbed topography was observed (Figure 15). Transects were completed by placing two stakes on either side of the rill or disturbed area. Stakes were placed in surfaces that were

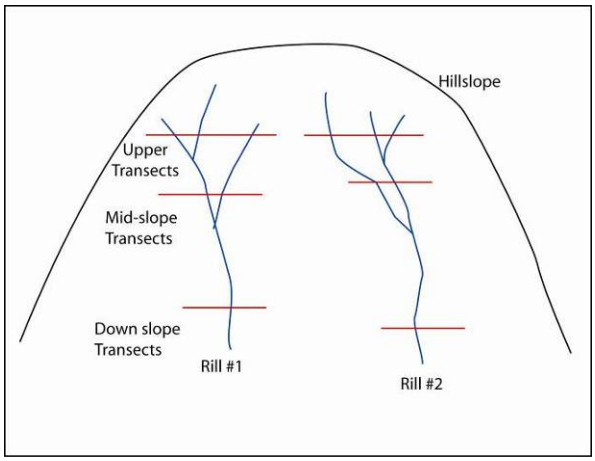

Figure 15. General schematic of transects of rills on hillslopes.

representative of the undisturbed, pre-fire hillslope surface. A level string was tied to both stakes, and measurements from the string to the hillslope surface were taken every 10 cm from stake to stake. Wherever possible transects were placed in areas that had evidence of pre- and post-fire features, such as burn lines on vegetation or ash layers to ascertain pre-fire topography. Longer transects were completed to incorporate the branching rill patterns seen on some of the hillslope, specifically in the upslope regions.

The unburned yucca-blackbrush hillslope had no rills or obvious surface disturbance so a set of transects a minimum of 4 m long was completed to measure general trends in soil distribution on the hillslopes. The burned yucca-blackbrush hillslope had a disturbed surface appearance with rills that tended to be short and poorly defined. Two sets of transects greater than 4 m long were completed in locations that incorporated rills and other areas that had surficial disturbances representative of the post-fire hillslope topography.

Mounds of sediment accumulation on the upslope side of vegetation were measured on the piñon and juniper trees on the piñon-juniper hillslopes and on blackbrush vegetation on the yucca-blackbrush hillslopes. Height, width, and length measurements were made on a minimum of nine plants, on each hillslope (Appendix 8). Height measurements were made from the apex of the mound to the undisturbed hillslope surface (Bochet et. al. 2000). In locations where the original surface had been disturbed the undisturbed surface elevation was estimated. The shape of the deposit and any additional observations regarding erosion or movement of the mound post-fire were noted. On both the burned hillslopes the level of the burn etch line on the blackbrush or piñon and juniper trees relative to the top of the sediment mound was measured and used as an indicator of post-fire sediment movement.

A mini-disk infiltrometer (Decagon Model #S) measuring 32 cm tall with a diameter of 3.1 cm was used to complete infiltration tests on all upslope and interspace soil pits at all four field sites. The upslope and interspace regions on each hillslope were expected to have the greatest contrast of particle size distribution, organic matter, and soil horizon development, which would be reflected in the infiltration rates. Infiltration tests

were completed in triplicate at two different tensions (-1 and -4 cm) on the surface of each upslope and interspace soil pit on all hillslopes. Level pads were made by lightly scraping the surface of the soil just above the soil pit to remove any surface disturbances; this generally resulted in the total removal of the C/O horizon, which is 1-2 cm thick in most places. A thin layer of moist fine-grained sand was laid onto the pad to create a uniform surface between the base of the infiltrometer and the soil surface, ensuring a strong contact between the rough soil surface and the rigid smooth base of the tension infiltrometer. Tests were run in sequence on the same pads, with the first test run at a supply water pressure head of -4 cm (higher tension, slower infiltration) and the second test was run at a supply pressure head of -1 cm (lower tension, faster infiltration). Infiltrometers were placed onto the pads and measurements were made every 15 seconds for the first 2 minutes and every 30 seconds following, until steady state conditions were attained. Tests run at a lower tension, supply water pressure head of -1 cm, were expected to have increased rates of infiltration than the tensions run at a higher tension, supply pressure head of -4 cm. Infiltration data sets were graphed and a linear regression of each data set was completed. Infiltration rates calculated at the lower supply tension (-1 cm) should always be faster than infiltration rates run at a higher supply tension at the same location, any tests run at a supply pressure head of -4 cm (higher tension) that had a greater infiltration rates than tests run at a supply pressure head of -1 cm (lower tension) were not considered in the final calculation of conductivity (Appendix 10). The raw infiltration data was analyzed using Ankeny et al.'s (1991) method of calculating infiltration from tensiometer data (Appendix 10). The average conductivity rates of the

triplicate set of each upslope and interspace soil pit were calculated for each of the four hillslopes (Appendix 10).

Cs-137 samples were collected from one interspace and one side slope soil pit on each of the four hillslopes and two sets of samples were collected at the base of the burned yucca-blackbrush hillslope where post-fire hillslope deposition had formed a small 3 x 5 m fan on a remnant terrace. Additional soil samples were collected on undisturbed surfaces, these samples were considered baseline samples. The baseline soils were collected in areas that had received no post-1950 sediment deposition. These surfaces were identified by an undisturbed surface appearance, degree of soil development, and vegetative surface cover. Bulk soil samples for Cs-137 analysis were collected every 5 cm down to 30 cm depth (based on data from Griffith et al. 2006) or to the AC/Cr horizon.

Cs-137 samples were analyzed using a multi-channel analyzer. Samples were generally run for one hour. After running a few sets of samples with various concentrations of Cs-137 a stronger criteria was developed for the length of time necessary for sample analysis. If after 1200 seconds the counts/second remained <5 counts/second the measurement was stopped. The criteria was based off the calculated counts per time necessary for a sample to have a high enough Cs-137 concentration to be considered useful in understanding sediment movement (a minimum of 0.10 pCi/g) (Appendix 11). After 1200 seconds sample counts generally reached a steady state, but samples were run for an additional 2400 seconds to lower the standard deviation.

4. Results

4.1 Vegetative coverage

The unburned piñon-juniper hillslope has moderate tree cover, with trees ranging from 4.5 to 6 m tall. Interspace areas have sparse ground cover consisting primarily of grasses and small shrubs (Figure 16a). Trees on the burned piñon-juniper slopes were severely burned, but at the time of this fieldwork none of the trees had fallen over post-fire. Small grasses and shrubs were beginning to grow back one year after the fire (Figure 16b).

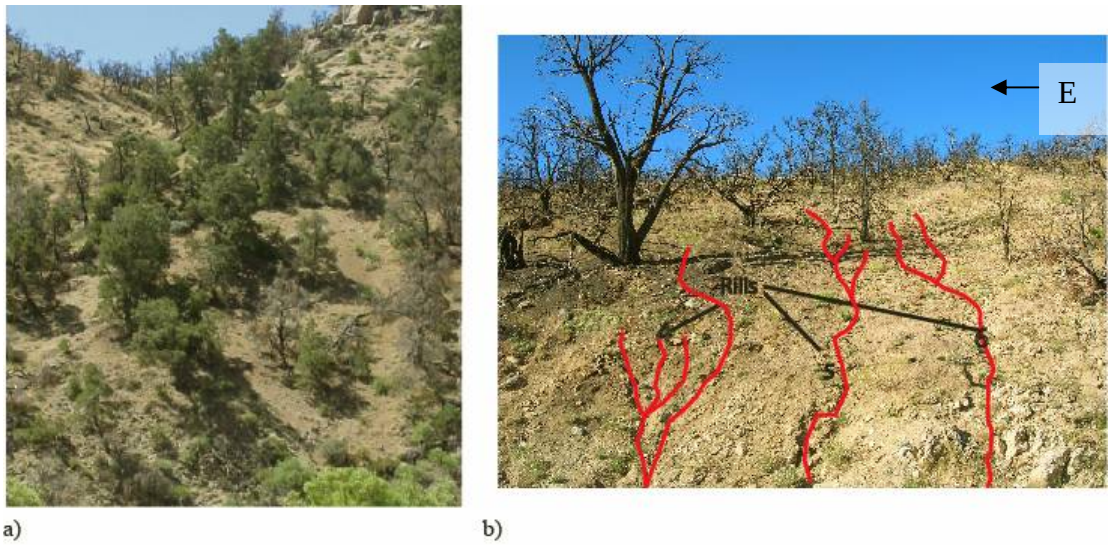

Figure 16. a) unburned piñon-juniper hillslope (north-facing), b) main rills on burned piñon-juniper hillslope (north-facing). Rill #3 is to the E and not visible on this picture. Red lines highlight numbered rills.

Vegetation consisting of yucca, joshua trees, blackbrush, cholla, ephedra, and other low lying shrubbery cover the unburned yucca-blackbrush hillslope (Figure 17a). The burned yucca-blackbrush hillslope still had some joshua trees and yuccas. The majority of the yuccas were completely disseminated; however, yuccas are very resilient to fire and were beginning to re-establish themselves on the burned hillslope one year post-fire (Figure 17b). Most of the other vegetation on the burned yucca-blackbrush

hillslope had been completely destroyed by the fire and only the remnant root systems burned to ground level were visible.

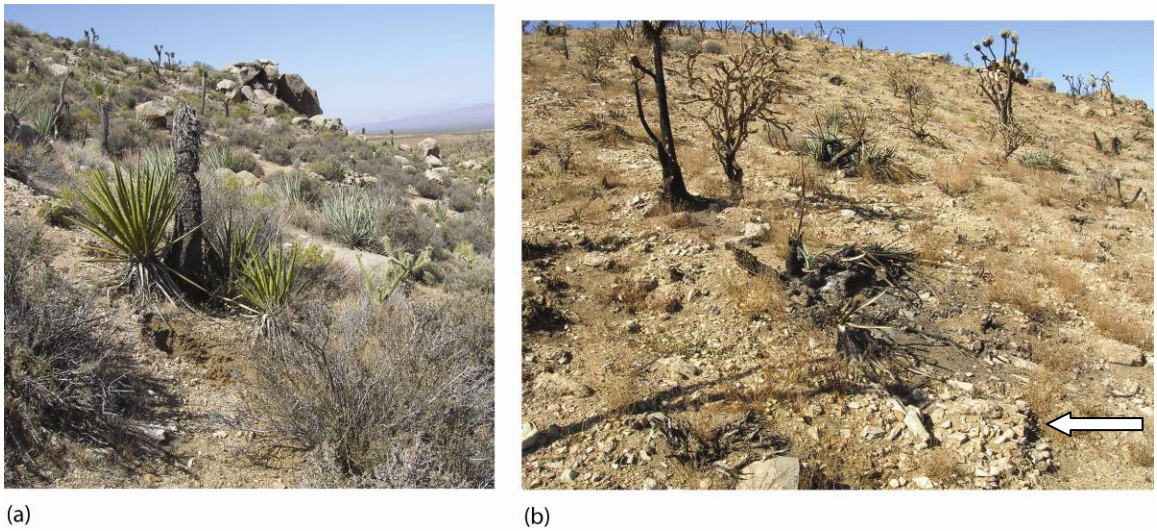

Figure 17. a) unburned piñon-juniper hillslope (north-facing) b) burned piñon-juniper hillslope (north-facing). White arrow points to disturbed surface appearance.

4.2 Surface topography

4.2.1 Rill formation and general topography of the hillslopes

Juniper and piñon needles and cones had accumulated in both rills formed on the unburned piñon-juniper hillslope indicating that the rills had experienced a period of relative stability. Rill #1 formed 5 m west of rill #2, both rills had similar vegetation and slope angle, but rill #1 was much narrower than rill #2 (Figure 18), the lower slope transects of both rills were shallower than the middle and upper transects even though slope angle remained the same. Rill #1 is much deeper than rill #2 and does not exhibit such a smoothed profile, likely indicative of more recent activity in rill #1 than in rill #2. No direct evidence was found to suggest that these rills were formed by a previous fire or other major disturbance on the hillslope. The overall topography of the unburned piñon-juniper hillslope was slightly convex.

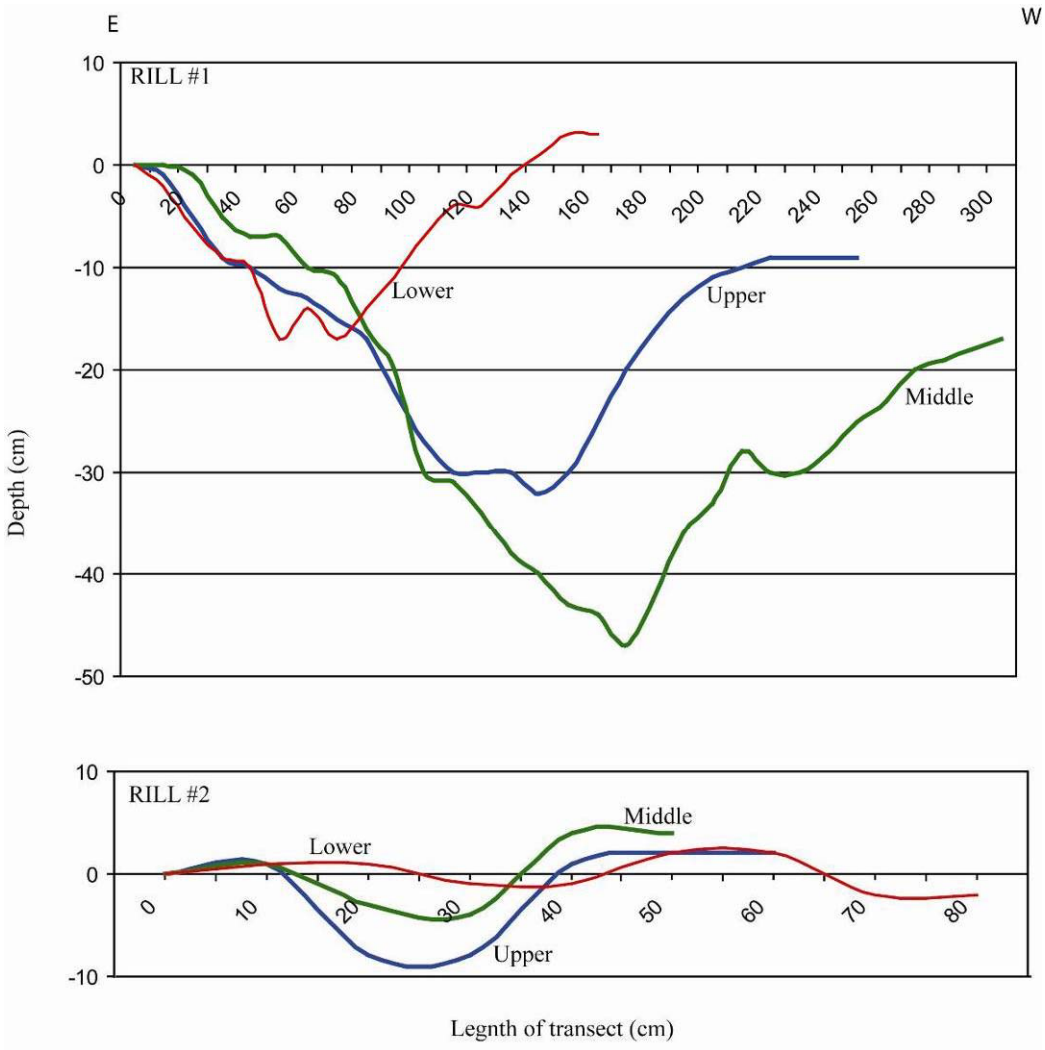

Figure 18. Transects of rills on unburned piñon-juniper hillslope.

Boxes on the transect lines represent pre-fire surfaces (Figures 19 and 21). Indicators of pre-fire surfaces on the transects illustrate that some of the rills on both burned hillslopes were formed pre-fire and were reactivated post-fire. The burned pinyon-juniper hillslope had visible rill activity, the bottom of the hillslope had four clearly defined rills which branch and become less well defined higher up on the hillslope

(Figure 19). The upper transects of rills #3 and #4 had no pre-fire surface indicators implying the subtle rill formation was likely post-fire. Pre-fire surface topography

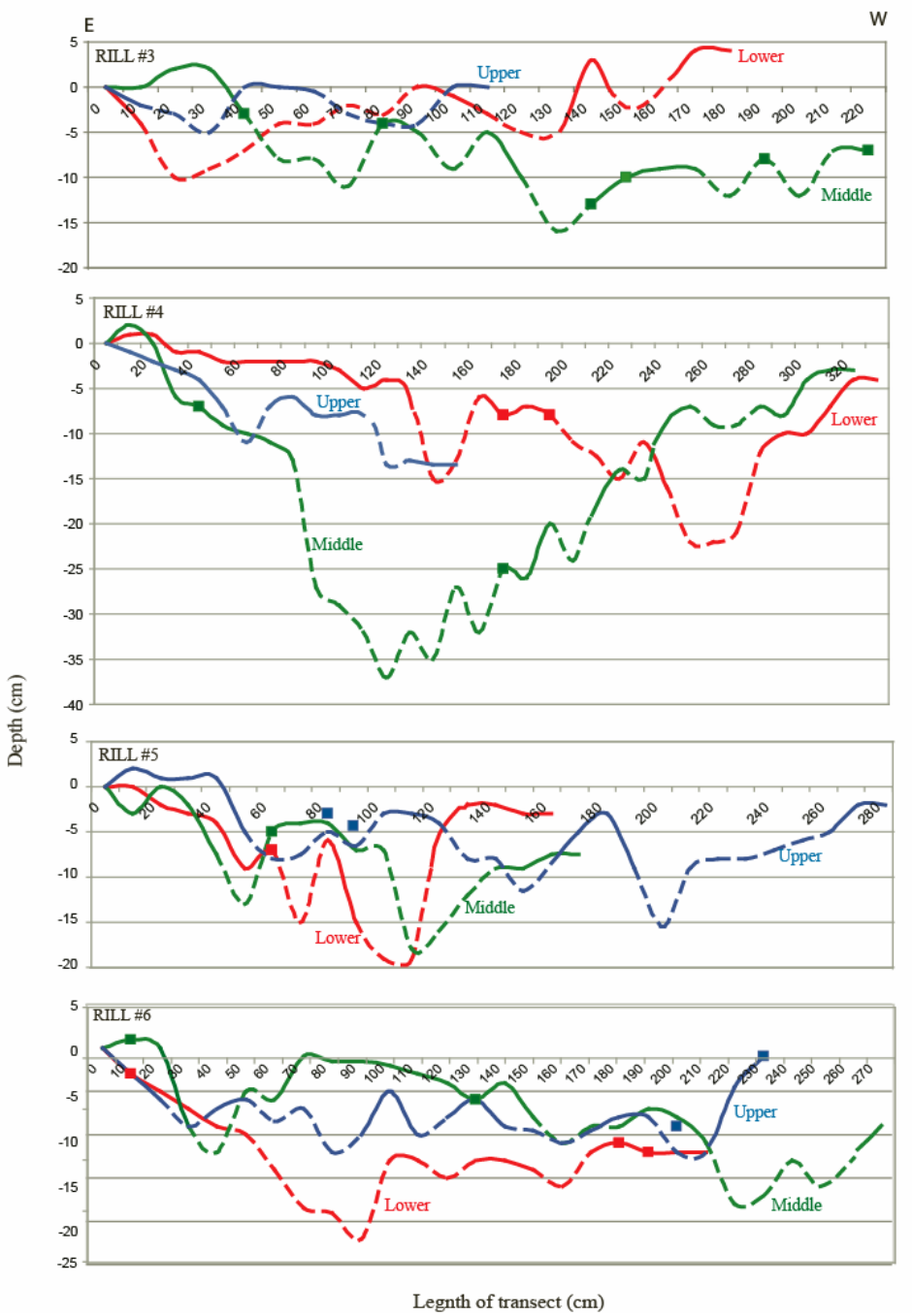

Figure 19. Transects of rills on the burned piñon-juniper hillslope. Boxes represent pre-burned surface elevation. Dashed lines represent locations of post-fire reactivation.

indicates that the middle transects on both rills #3 and #4 had some pre-fire rill formation and that post-fire erosional activity likely reactivated these areas, deepening rills that were already present on the hillslope. The lower transect of rill #4 shows some disturbance, including two well defined rills; however, pre-fire surface topography suggests that some low points were already present along this transect. Lower transect profiles of rills #5 and #6 have more incision relative to the upper and middle transects, this pattern is associated with rills that are reactivated and begin to propagate upslope. Both lower transects have some pre-fire surface indicators that imply some low points already existed along the transect profiles. Pre-fire topography indicates that the middle transect of rills #5 and #6 may not have had significant pre-fire variance in topography, indicating most down cutting and erosion occurred on the middle portion of the transects post-fire. The upper portion of rills #5 and #6 had vegetation with burn etch lines approximately 2 cm above the surface indicating 2 cm of sediment removal occurred along portions of this transect. All four rills on the burned yucca-blackbrush hillslope experienced significantly less disturbance in the upper transects compared to the lower transects, where as the mid-slope transects tended to vary in depth and degree of disturbance.

The unburned yucca-blackbrush hillslope had the most stable surface appearance, no rills were observed on this hillslope. The hillslope is cut by granitic veins that are more susceptible to erosion than the surrounding bedrock. The susceptibility to erosion of these veins has caused them to incise into the hillslope forming small (<2 m wide) channels. Transects were completed up the center of the hillslope in order to identify the general hillslope topography. All three transects climb gradually to the west, although

the end of the upper transect drops down approximately level with the initial surface level (Figure 20). Transect profiles, especially along the middle and upper transects, capture low points that in profile look like rills, it is possible that the transects may be capturing old rills that are not perceptible when walking across the hillslope surface.

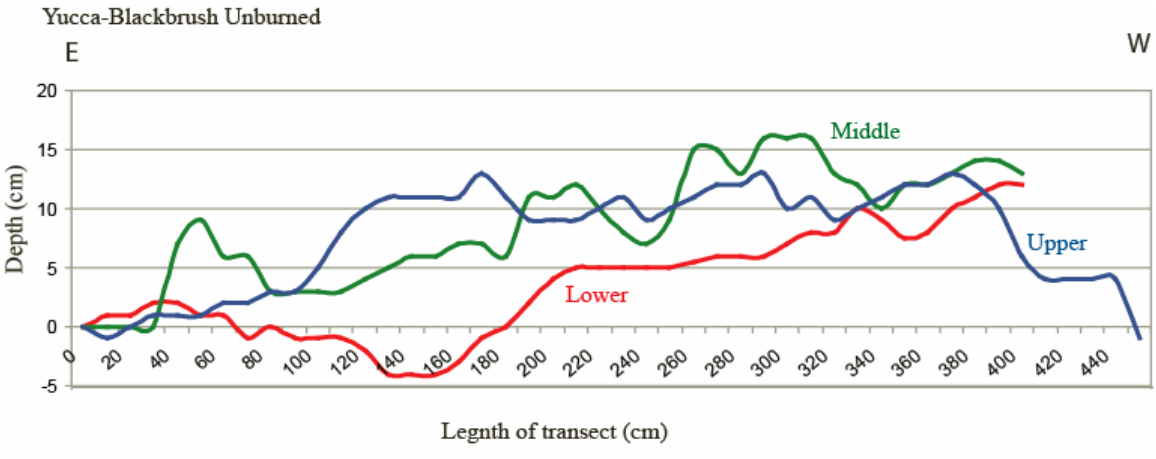

Figure 20. Transect of unburned yucca-blackbrush hillslope topography.

The burned yucca-blackbrush hillslope had a disturbed appearance. Rills covered the surface but tended to be very short in length circling plant mounds, and then becoming very shallow. Transects on this hillslope were completed across areas with the most disturbed surface appearances, capturing the most defined rill segments to illustrate the general topography of the hillslope (Figure 21). Rill #7 is representative of the disturbed nature of the hillslope. Pre-fire surface indicators along all three transects of rill #7 imply pre-fire rills existed along the transects and post-fire erosion resulted in reactivation and down cutting of the rills. Transects of rill #8 identified wider deeper rills than rill #7, and the overall topography did not appear as disturbed. Pre-fire surface topography along the lower and upper transects profiles of rill #8 imply that some of the

low points were pre-fire surfaces, the deep rill in the middle transect appears to have been a post-fire occurrence.

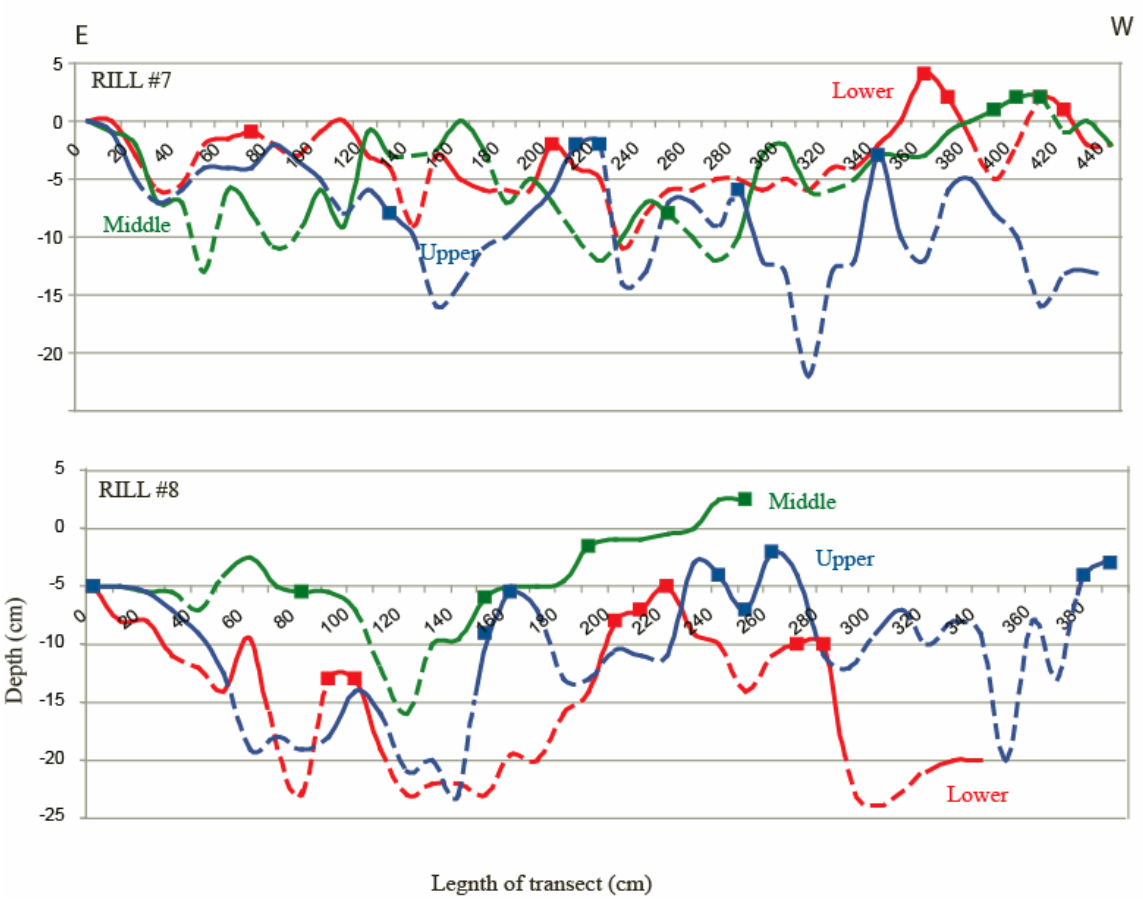

Figure 21. Transects of rills on burned yucca-blackbrush hillslope. Boxes represent pre-burned surface elevation. Dashed lines represent locations of post-fire reactivation.

On both the burned hillslopes pre-fire surface indicators imply that at least some of the rills existed prior to the 2005 fire. No record of previous fires exists for these hillslopes indicating pre-fire rills likely formed due to factors other than fire.

4.2.2 Sediment accumulation and deposition on hillslopes

Initial observations on burned hillslopes helped to identify surfaces that appeared to have undergone substantial sediment movement, however very little evidence of

sediment removed from hillslopes was observed. The only location where hillslope sediment movement from the hillslopes was identified was a 3 x 5 m fan deposited onto a terrace remnant, at the toe of the burned yucca-blackbrush hillslope. Measurement of burn etch lines on 10 plants on the remnant terrace identified ~10 cm of post-fire deposition over the entire fan. Although the burned hillslopes appeared highly disturbed, deposition off the hillslope was only observed at this one location.

Measurement of mound heights on the upslope side of vegetation on the burned and unburned hillslopes found an average increased mound height of 6 cm on the burned piñon-juniper hillslope compared to the unburned piñon-juniper hillslope (Figure 22).

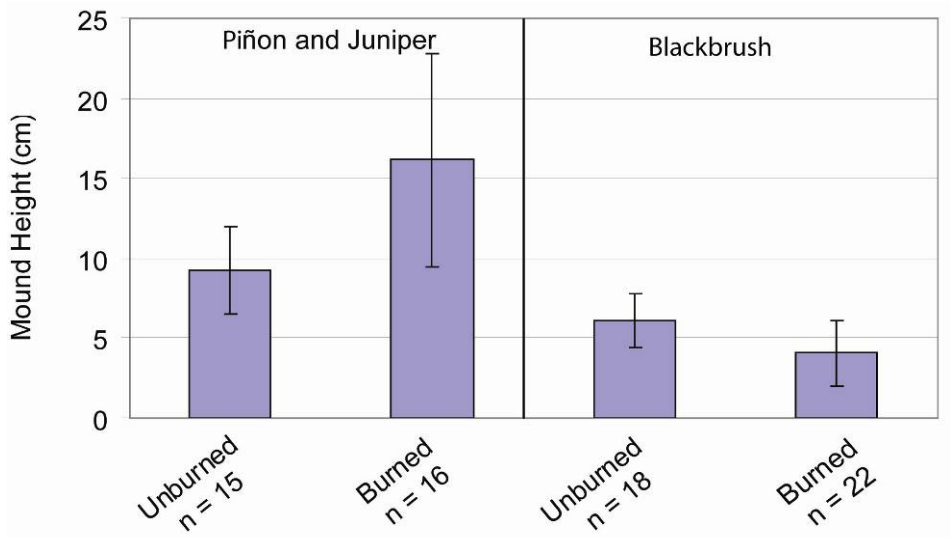

Figure 22. Measurement of height of the mound associated with piñon trees and blackbrush bushes on the corresponding hillslopes.

Mounds on the burned piñon-juniper hillslope lacked any accumulation of organic matter or debris on the top of the mounds indicating that at least the top sediment layer had been deposited post-fire. Measurements of sediment thickness relative to the burn etch line on juniper and piñon trees indicated that 12 cm of post-fire sediment had been deposited against the tress (Figure 23). Mounds on the burned yucca-blackbrush hillslope tended to

be approximately 2 cm lower than on the unburned yucca-blackbrush hillslopes (Figure 22). Measurements of sediment level relative to the burn etch lines on burned yucca-blackbrush hillslope identified an average of 1 cm of post-fire deposition on the upslope side of the blackbrush vegetation (Figure 23).

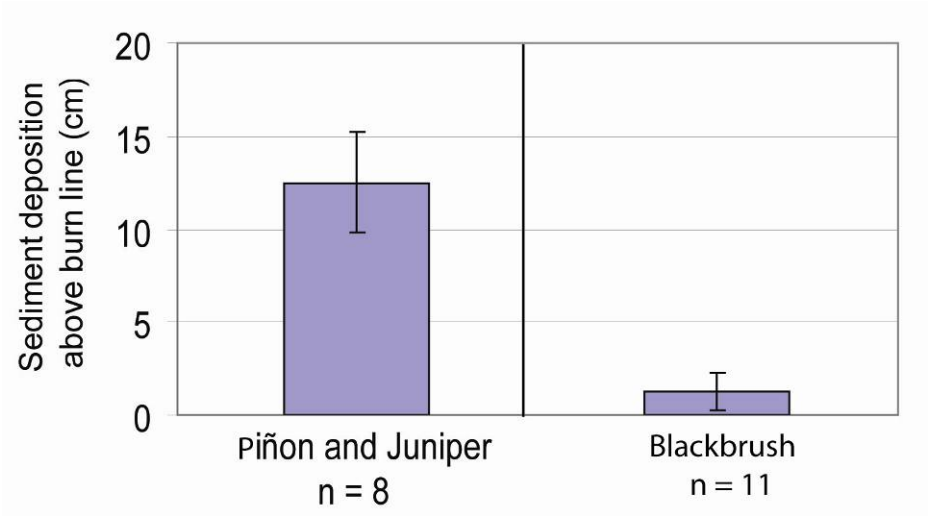

Figure 23. Post-fire sediment deposition above burn etch line.

4.3 Hillslope soils

4.3.1 Soil thickness and horizon development

Throughout all four field sites, regardless of canopy-interspace location of the soil pits on the hillslopes, all soil pits had very similar soil development and soil profile descriptions (Table 5, Appendix 6). Almost all soils pits consisted of four horizons that had a surface horizon composed of a thin veneer (1-4 cm) of gruss mixed with 2-8 % fine organic matter and minimal soil structure (Figure 24). The surface horizon had too much coarse organic litter to be considered an A-horizon. Due to the high amount of gravel mixed with coarse organic matter it was determined that C/O-horizon nomenclature best fit the surface horizon. The two horizons directly below the C/O-horizon were A-

horizons (A1 and A2); both horizons had very similar soil properties consisting of crumbly and fairly loose structure (Table 5). The only visible distinction between

Table 5. General soil profile characteristics for key soil pits and horizons on all four hillslopes.

Site location	Horizon	colors (dry)	colors (wet)	horizon thickness	Texture			Fine organic matter (%)	Notes
					Gravel (%)	Sand (%)	Silt (%)		
Piñon-juniper hillslope unburned Sideslope (Pit #7)	C/O	10 YR 3/2	10 YR 2/1	4	40.2			10.2	
	A1	10 YR 5/4	10 YR 4/4	6	34.4	50.6	15.0	3.1	
	A2	10 YR 5/4	10 YR 4/4	14	35.9	49.1	15.0	1.7	
	Cr	10 YR 6/3	10 YR 5/3	31+				0.4*	
Piñon-juniper hillslope burned Sideslope (Pit #23)	C/O	10 YR 2/1	10 YR 2/1	1	66.6			7.4	burned layer observed in top 2 cm
	A1	10 YR 4/2	10 YR 3/2	4	41.6	43.5	14.9	3.5	
	A2	10 YR 5/4	10 YR 3/3	10	40.4	38.8	20.9	1.8	
	Cr	10 YR 6/3	10 YR 5/3	15+				4.1	
Yucca-blackbrush hillslope unburned Sideslope (Pit #43)	C/O	10 YR 5/3	10 YR 3/2	1	57.7			2.5	
	A1	10 YR 5/3	10 YR 3/2	8	45.2	39.4	15.4	2.1	
	A2	10 YR 5/3	10 YR 3/2	12	41.9	41.8	16.3	1.4	
	AC	10 YR 5/3	10 YR 3/2	9+				1.9	
Yucca-blackbrush hillslope burned Sideslope (Pit #27)	C/O	10 YR 4/2	10 YR 2/2	1	51.0			3.5	burned layer observed in top 2 cm
	A1	10 YR 4/3	10 YR 2/1	4	14.6	60.8	24.6	3.9	
	A2	10 YR 5/3	10 YR 3/2	18	43.2	35.9	20.8	2.6	
	AC	10 YR 4/3	10 YR 4/3	15+				1.5**	

* measurment extrapolated from Pit #3
** measumrent extrapolated from Pit #26

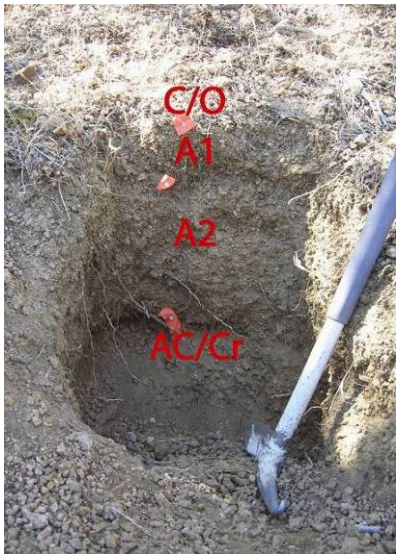

Figure 24. Representative soil profile illustrating the horizonation in an interspace soil pit on the unburned piñon-juniper hillslope.

the A-horizons was a very subtle change in bedding and in some cases a slight color distinction. On the piñon-juniper hillslopes the A-horizons generally develop on top of highly weathered granitic bedrock, which is sapprolitic in places forming a Cr-horizon, where as A-horizons on the yucca-blackbrush hillslopes tend to form on top of A/C horizons. The only visible distinction between the burned and unburned soil pits was a burned layer in the top 2-5 cm of the canopy soil profiles.

Variability of sediment thickness was minimal among canopy-interspaces soil pit locations on each hillslope. The average soil thickness above the AC/Cr horizon ranges considerably among the four field sites, from a low of 12 ± 5 cm on the unburned yucca-blackbrush hillslope to a high of 48 ± 4 cm on the unburned piñon-juniper hillslope. The interspace soil pits on both the burned and unburned piñon-juniper hillslopes had the thickest sediment accumulation relative to under canopy soils (Table 6).

Table 6. Sediment thickness above the AC/Cr horizon boundary.

Site location	Upslope (cm)	Side slope (cm)	Down slope (cm)	Interspace (cm)	slope angle (degrees)
	± 1 sigma				
Piñon-juniper hillslopes					
Unburned	38 ± 7	35 ± 18	35 ± 20	41 ± 35	45
Burned	16 ± 4	17 ± 3	13 ± 3	18 ± 8	24
Yucca-blackbrush hillslopes					
Unburned	13 ± 4	12 ± 5	17 ± 9	14 ± 2	17
Burned	32 ± 4	37 ± 12	32 ± 19	33 ± 15	22

Evidence of an old burn was identified during excavation of soil pits on the unburned piñon-juniper hillslope (Appendix 6). One down slope soil pit (Pit 5) and two interspace soil pits (Pits 12 and 13) had large roots (10 cm diameter) present at 20–40 cm

depth that had burned exteriors, Pit 13 also had a 5 cm^2 ash pocket at 50 cm depth. The burned roots were singed on the top, indicating they were at the surface at the time of the fire. The roots were associated with piñon and juniper trees approximately 5 m tall. No age estimates were available for these trees, nor is there any historical record of this fire.

4.3.2 Lab analysis of particle size data

The weighted averages for horizon thickness of particle size and LOI data for the A1- and A2-horizons were completed for each set of soil pits on each hillslope (i.e. upslope, side slope, etc.). Results indicate similar particle size and LOI distribution between the A1- and A2-horizons of each set of canopy or interspace soil pits on each hillslope (Tables 7 and 8). Because the results were so similar, the A1- and A2-horizons were averaged together to streamline data presentation. For the rest of the paper the A1- and A-2 horizons will be referred to as the A-horizon and the combined averages of the A1- and A2-horizons will be presented and discussed simply as the A-horizon.

Table 7. LOI, whole soil particle size, and horizon thickness data for the piñon-juniper hillslopes.

					Weighted averages over all three soil pits at each location on the hillslopes							
	Site	Horizon**	Average horizon thickness		Sand*		Fines*		Gravel*		LOI*	
			(cm)	stdev.	(%)	std.dev	(%)	std.dev	(%)	std.dev	(%)	std.dev
			standard deviation ± 1 sigma									
Piñon-juniper hillslope												
Unburned	Upslope	C/O	5	4					65	26	10	12
		A1	13	4	31	5	11	4	58	9	3	2
		A2	20	15	21	8	7	3	72	11	2	0
		A1 + A2*	**16**	**5**	**26**	**7**	**9**	**3**	**65**	**10**	**3**	**1**
	Side slope	C/O	5	3					61	23	13	9
		A1	5	7	33	13	12	3	55	16	3	0
		A2	18	2	33	14	12	2	55	16	2	1
		A1 + A2*	**12**	**9**	**33**	**0**	**12**	**0**	**55**	**0**	**3**	**0**
	Down slope	C/O	5	4					64	27	13	6
		A1	5	6	39	10	12	5	49	14	7	4
		A2	5	6	36	4	14	1	50	5	4	3
		A1 + A2*	**5**	**0**	**37**	**2**	**13**	**2**	**50**	**0**	**5**	**2**
	Interspace	C/O	6	9					61	9	2	1
		A1	12	1	25	7	8	2	67	9	3	2
		A2	24	16	31	2	10	0	59	1	2	0
		A1 + A2*	**18**	**8**	**28**	**4**	**9**	**1**	**63**	**5**	**3**	**1**
Burned	Upslope	C/O	1	1					58	12	4	1
		A1	4	1	46	4	20	4	33	7	3	0
		A2	11	7	34	7	17	2	48	9	3	1
		A1 + A2*	**7**	**5**	**40**	**9**	**19**	**2**	**41**	**11**	**3**	**1**
	Side slope	C/O	1	1					57	9	4	3
		A1	4	1	53	8	22	7	25	14	3	1
		A2	12	2	39	1	23	2	38	2	2	0
		A1 + A2*	**8**	**5**	**46**	**10**	**23**	**1**	**32**	**9**	**3**	**1**
	Down slope	C/O	2	1					44	6	5	3
		A1	6	3	40	17	22	9	38	26	4	2
		A2	9	0	36	1	22	6	41	5	2	1
		A1 + A2*	**8**	**2**	**38**	**3**	**22**	**0**	**39**	**2**	**3**	**1**
	Interspace	C/O	1	1					72	4	5	3
		A1	8	5	45	4	17	1	37	4	2	0
		A2	9	3	28	9	18	2	54	11	3	0
		A1 + A2*	**8**	**1**	**37**	**12**	**18**	**1**	**46**	**12**	**3**	**0**

*note A1+A2 data is the average of the weighted average of the two individiual horizons

** The AC/Cr horizons are not included on this table because particle size analysis was not completed on these horizons

Table 8. LOI, whole soil particle size, and horizon thickness for the yucca-blackbrush hillslopes.

	Site	Horizon**	Average horizon thickness		Sand		Fines		Gravel		LOI	
			(cm)	stdev.	(%)	std.dev	(%)	std.dev	(%)	std.dev	(%)	std.dev
			standard deviation ± 1 sigma									
	Yucca-blackbrush hillslope											
	Upslope	C/O	1	0					65	3	4	1
		A1	4	1	41	6	14	2	45	8	2	0
		A2	15	6	36	3	13	2	51	5	2	0
		A1 + A2*	**10**	**8**	**38**	**4**	**14**	**0**	**48**	**4**	**2**	**0**
Unburned	Side slope	C/O	1	0					64	6	3	0
		A1	5	2	42	6	16	3	42	8	2	0
		A2	21	13	39	2	20	6	40	7	2	1
		A1 + A2*	**13**	**11**	**41**	**2**	**18**	**3**	**41**	**1**	**2**	**0**
	Down slope	C/O	1	0					65	13	3	1
		A1	4	3	44	8	16	2	40	10	2	0
		A2	12	3	40	5	19	1	42	6	2	0
		A1 + A2*	**8**	**5**	**42**	**3**	**17**	**1**	**41**	**1**	**2**	**0**
	Interspace	C/O	1	0					72	4	3	1
		A1	7	1	46	4	15	2	39	6	2	0
		A2	10	6	42	1	16	1	42	2	2	0
		A1 + A2*	**8**	**2**	**44**	**3**	**16**	**0**	**40**	**2**	**2**	**0**
	Upslope	C/O	1	0					44	3	2	0
		A1	5	2	49	6	18	1	33	6	2	0
		A2	8	2	39	3	19	4	42	8	2	0
		A1 + A2*	**6**	**2**	**44**	**7**	**19**	**1**	**37**	**6**	**2**	**0**
	Side slope	C/O	1	0					58	17	3	1
Burned		A1	5	1	55	4	24	3	20	5	2	0
		A2	14	6	34	3	18	6	48	10	2	70
		A1 + A2*	**9**	**6**	**45**	**15**	**21**	**5**	**34**	**20**	**2**	**0**
	Down slope	C/O	1	1					49	15	4	n/a
		A1	6	3	43	18	19	7	38	26	4	3
		A2	10	6	45	10	21	2	35	11	2	1
		A1 + A2*	**8**	**3**	**44**	**1**	**20**	**1**	**36**	**2**	**3**	**1**
	Interspace	C/O	1	0					55	22	2	0
		A1	9	3	46	6	19	1	35	7	2	0
		A2	17	6	36	6	16	5	48	11	3	2
		A1 + A2*	**13**	**5**	**41**	**7**	**17**	**2**	**42**	**9**	**2**	**1**

*note A1+A2 data is the average of the weighted average of the two individiual horizons

** The AC/Cr horizons are not included on this table because particle size analysis was not completed on these horizons

On all four hillslopes the C/O horizon tended to have greater gravel content than the A-horizon, this suggests that the C/O horizon formed recently due to mixing of gruss with the underlying A-horizon. The C/O-horizon and A-horizon tended to have less gravel on the burned hillslopes than the unburned hillslopes for all canopy-interspace locations within both ecotones (Figures 25 and 26). On the burned yucca-blackbrush

hillslope the down slope and interspace soil pits had greater gravel content in the A-horizon than their analogous unburned soil pits (Figure 26).

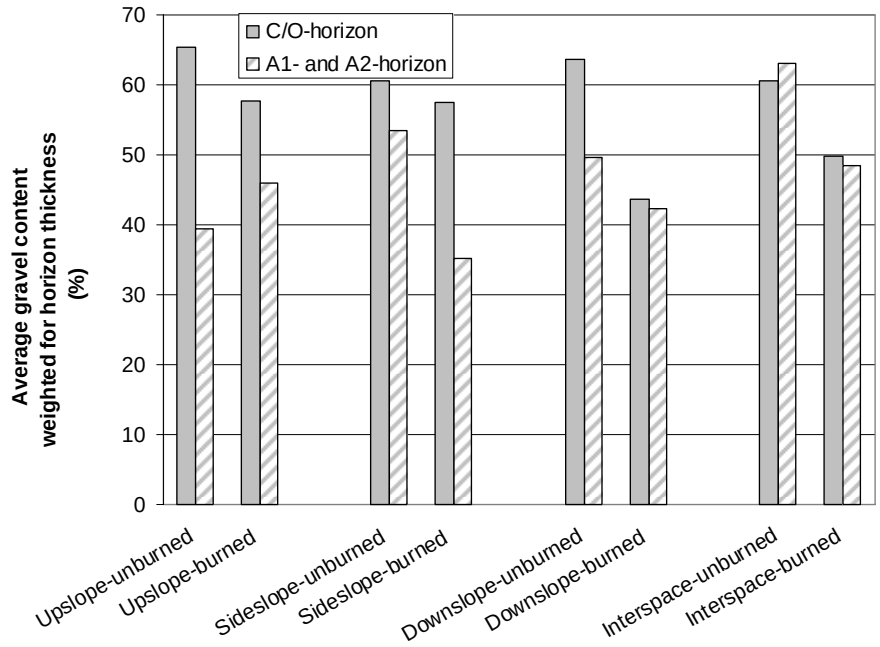

Figure 25. Weighted average of the percent gravel in the C/O-horizon and A-horizon in the piñon-juniper soil pits.

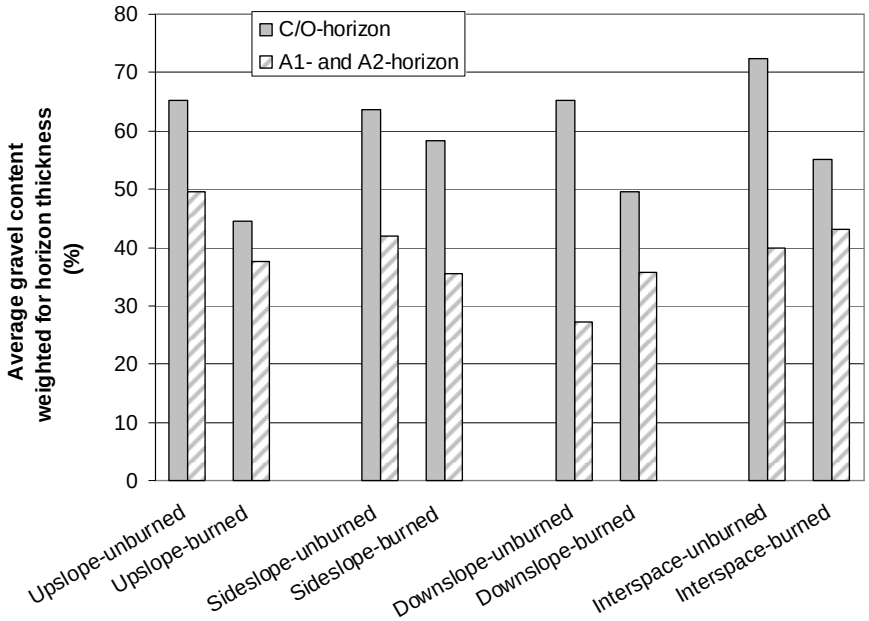

Figure 26. Weighted average of the percent gravel in the C/O-horizon and A -horizon in the yucca-blackbrush soil pits.

4.4 Infiltration on hillslope soils

Infiltration measurements on burned and unburned hillslopes provided information on localized rates of infiltration at interspace regions and upslope regions of canopies on the hillslopes. Infiltration rates at both supply pressure heads (-1 and -4 cm) were rapid and there was not a considerable change in infiltration rates between the burned and unburned hillslopes (Table 9). Particle size distribution was similar on all hillslopes (Figure 27) and did not appear to be dependent on canopy-interspace soil pit locations and thus did not impact infiltration rates at different location on the hillslopes. Minimal variation of the infiltration rates on burned versus unburned hillslopes indicates that the June 2005 fire had minimal impact on soil properties that control infiltration rates of soils.

Table 9. Mean infiltration rates for field sites

		Infiltration Rates			
Site		**K(-4) (cm/hr)**	Std. dev.	**K(-1) (cm/hr)**	Std. dev.
Piñon-Juniper Hillslope - Unburned	Upslope	**4.79**	2.53	**16.53**	6.74
	Interspace	**2.59**	1.39	**17.01**	9.02
Piñon-Juniper Hillslope - Burned	Upslope	**3.69**	1.68	**8.98**	5.24
	Interspace	**3.15**	3.06	**10.91**	7.98
Yucca-Blackbrush Hillslope - Unburned	Upslope	**2.76**	0.59	**6.74**	2.41
	Interspace	**4.95**	1.38	**15.11**	6.91
Yucca-Blackbrush Hillslope - Burned	Upslope	**4.59**	1.66	**9.56**	4.59
	Interspace	**3.65**	1.14	**7.22**	2.96

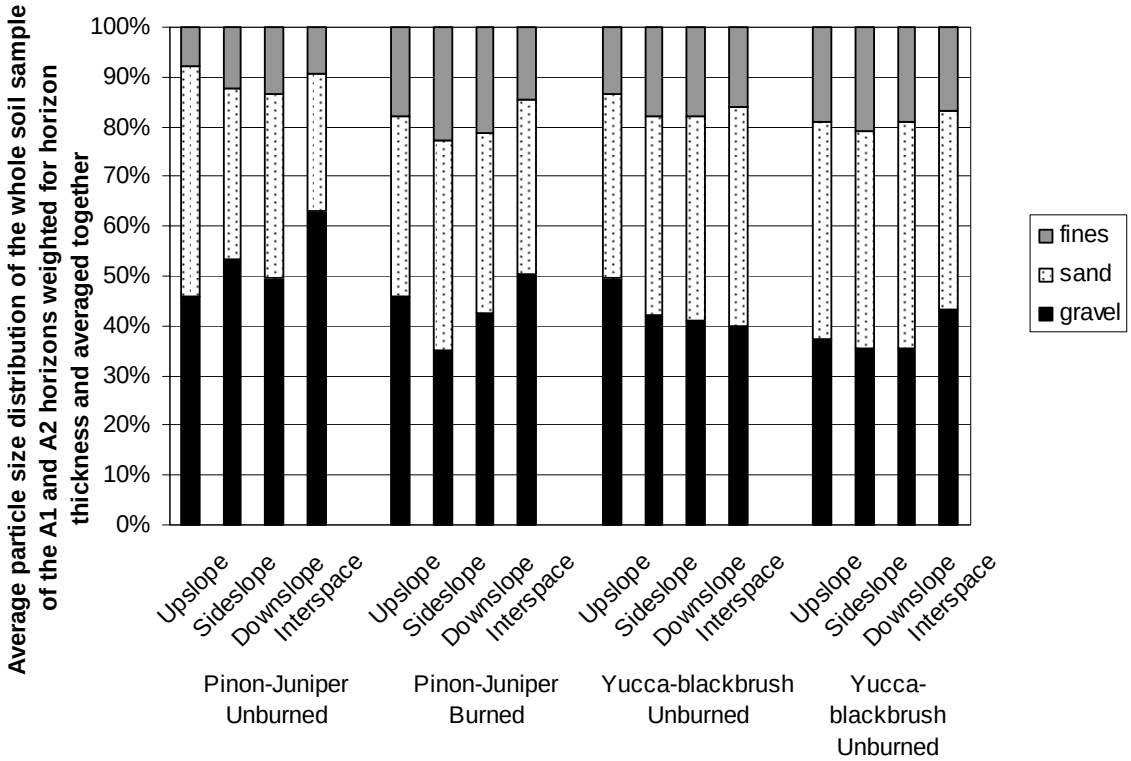

Figure 27. Weighted averages of the particle size distribution in the A-horizon from all soil pits on each hillslope.

4.5 Fine organic matter content of soils

The burned and unburned piñon-juniper hillslopes had a greater amount of fine organic matter than the yucca-blackbrush burned and unburned hillslopes. Soils below the canopy of the trees on the burned piñon-juniper hillslope had considerably less fine organic matter content relative to the unburned soils (Figures 28 and 29). The burned interspace soils on the piñon-juniper hillslope had increased fine organic matter content in the C/O- and A-horizon, relative to the unburned piñon-juniper hillslope (Figure 28). With the exception of the down slope soil pits on the piñon-juniper hillslopes the A-horizon on the burned hillslopes, had increased amounts of fine organic matter content when compared to the A-horizon of the unburned hillslopes.

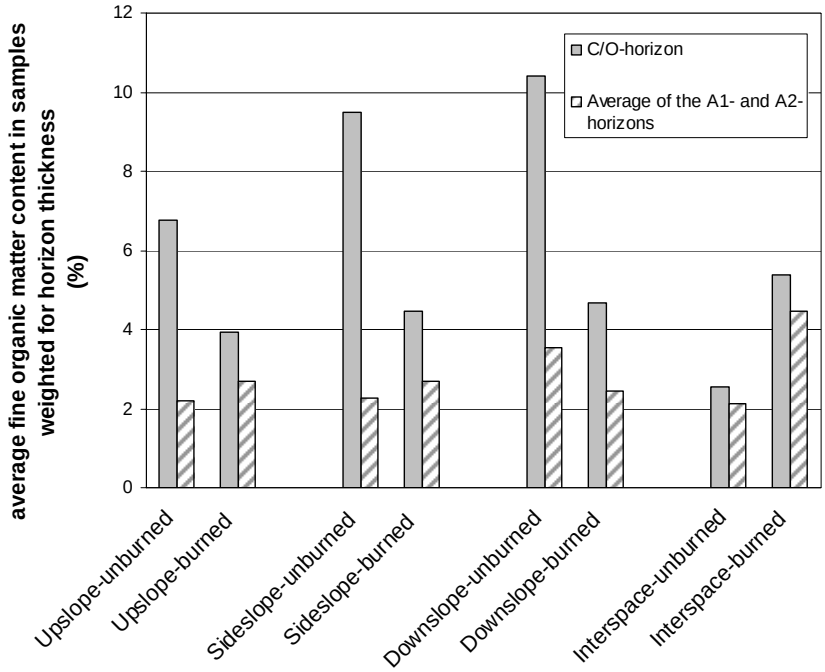

Figure 28. Average weighted percent of fine organic matter (adjusted for the fine organic matter measured in the Cr-horizon) throughout soil horizons on the piñon-juniper hillslopes.

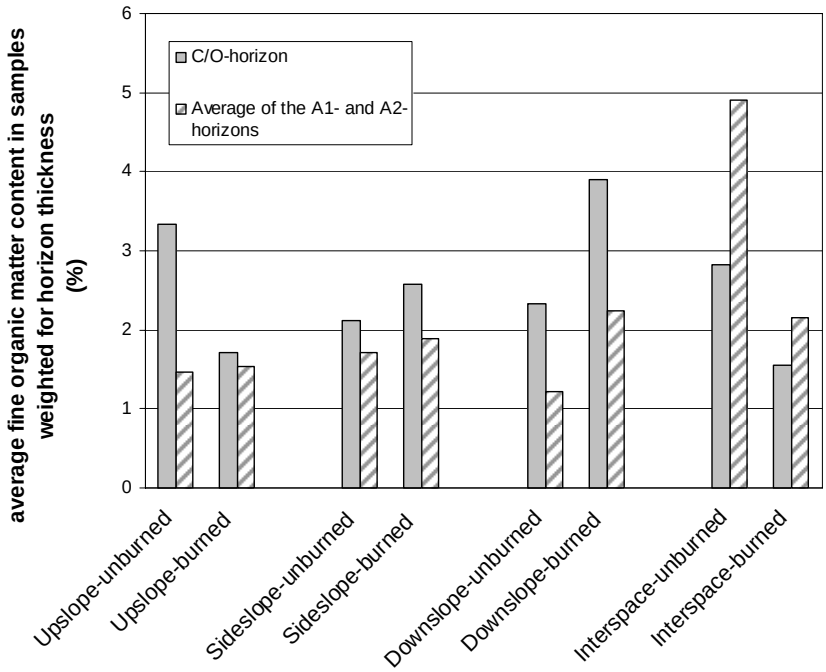

Figure 29. Average weighted percent of fine organic matter (adjusted for the fine organic matter measured in the Cr-horizon) throughout soil horizons on the yucca-blackbrush hillslopes.

The yucca-blackbrush hillslopes had significant variation in the content of fine organic matter in soil horizons at canopy-interspace locations on the hillslope (Figure 29). Soil pits surrounding the canopies on the burned and unburned yucca-blackbrush hillslopes had increased fine-organic matter in the C/O-horizon compared to the A-horizon. The burned side slope and down slope soil pits had increased organic matter in their C/O-horizon and A-horizons when compared to their analogous unburned soil pits. Both the burned and unburned interspace soil pits on the yucca-blackbrush hillslopes had greater organic matter in the C/O-horizon than in the A-horizons.

Greater fine organic matter in the C/O-horizon compared to the A-horizon may be correlated to gravel forming from grussifying bedrock on the outcrops toward the top of the hillslope. As gravel moves down slope (due to gravity, disturbance by animals, etc.) it picks up fine organic matter, forming the highly mixed C/O-horizon, this may explain why the C/O-horizon has more fine organic matter than the A-horizon.

4.6 Cesium-137 soil profiles

The first few sets of Cs-137 samples were analyzed to 30 cm depth. Based on the Cs-137 concentrations from these profiles it was determined that it was highly unlikely to find Cs-137 concentrations below 15 cm, so subsequent samples were analyzed from the surface to 15 cm depth.

Cs-137 concentrations in the baseline soils were relatively low (<0.25 pCi/g), with the peak concentration occurring between 5-10 cm, likely a result of Cs-137 binding to clay particles, which experienced some post-1950 translocation (Figure 30). Cs-137

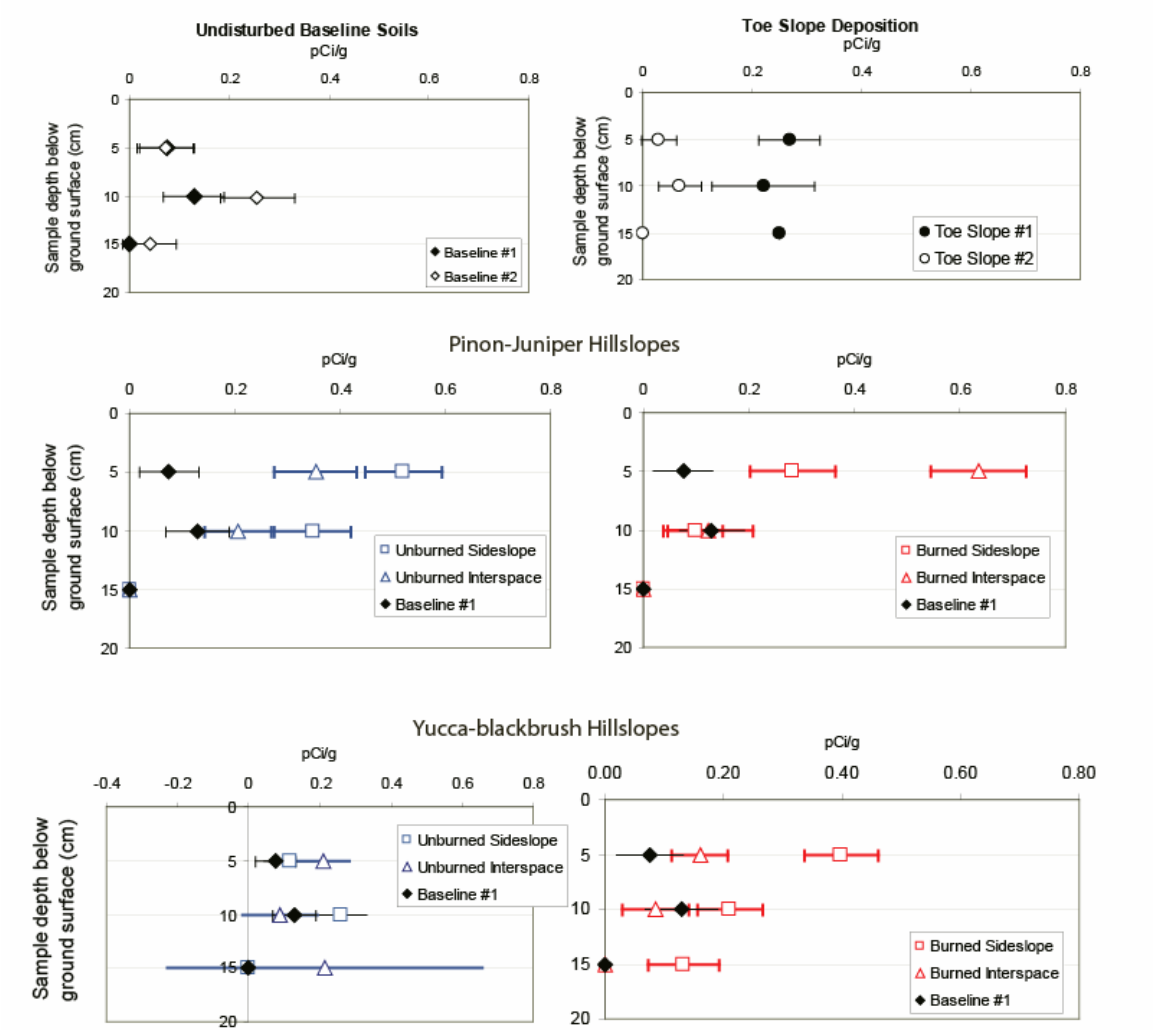

Figure 30. Cs-137 concentrations in the top 15 cm of specific soils.

concentrations in the baseline #1 soils compared to the Cs-137 concentrations in the burned and unburned piñon-juniper hillslopes indicates that the top 0-5 cm on both the canopy and interspace locations of the burned and unburned piñon-juniper hillslopes have received some post-1950 sediment deposition. The unburned piñon-juniper hillslope had higher Cs-137 concentrations with depth at both the canopy and interspace locations than the burned piñon-juniper hillslope.

The unburned yucca-blackbrush hillslope had the most stable surface appearance of any of the hillslopes. Cs-137 concentrations were expected to be very similar to the Cs-137 concentration of the baseline soils. Cs-137 concentrations in the unburned yucca-blackbrush side slope pit were very similar to the baseline # 1 concentrations. Cs-137 concentrations on the burned yucca-blackbrush hillslope were not as high as the concentrations measured on the piñon-juniper hillslopes, but the same trends of decreasing Cs-137 concentrations with depth were present. Both the piñon-juniper and yucca-blackbrush hillslopes have increased concentrations of Cs-137 in the top 10 cm of the soil. This is indicative of post-1960 sediment movement on both hillslopes that is not solely the result of loss of sediment stability due to the June 2005 fire.

The two Cs-137 profiles on the toe slope region of the burned yucca-blackbrush hillslope, where post-fire sediment movement from the hillslope was observed, had differing Cs-137 concentrations. Toe slope #1 had minimal Cs-137 concentrations throughout the profile, where as toe slope #2 had uniform Cs-137 concentrations throughout the top 15 cm of the profile, below 15 cm the Cs-137 concentration in toe slope #2 drops to 0.0 pCi/g (Appendix 10). The Cs-137 concentrations throughout toe slope #2 indicate constant post-1960 deposition of sediment from the hillslope onto the toe slope region.

4.7 Analysis of precipitation data

Precipitation data (1958-2006) was analyzed and storms that generated 5 cm or more precipitation per 24 hour period were recorded along with the date of storm occurrence. The month of the storm was used to generally identify whether the storms

were frontal or convective events (Figure 31). Precipitation exceeding 5 cm occurred 23 times during the last 48 years. Nine of these events were associated with frontal storms and fourteen were associated with convective storms. One of the frontal storms and three of the convective storms lasted for 48 hours or more, dropping at least 5 cm of

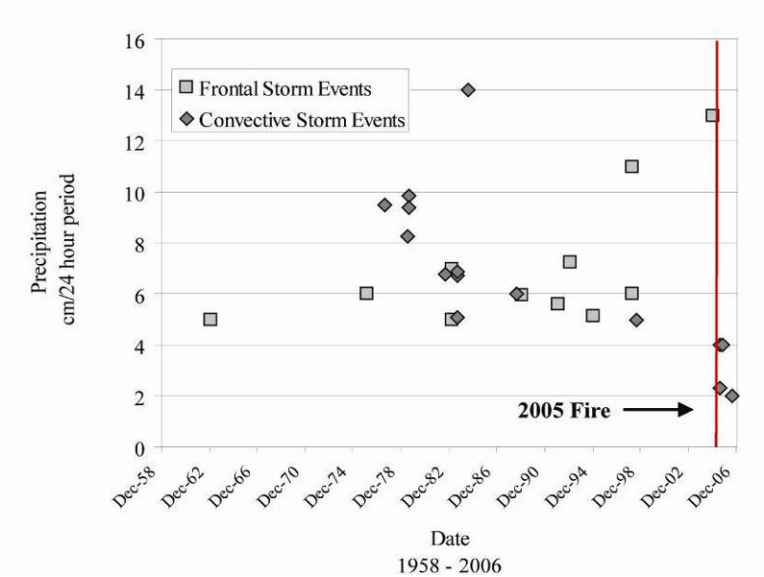

Figure 31. Storm events between 1958 and 2006 which resulted in greater than 5 cm precipitation over a 24 hour period and the four post-fire events that produced at least 2 cm precipitation over a 24 hour period.

precipitation over a 24 hour period for multiple days in a row. All but two of the convective storms occurred between 1977 and 1984. Three storms over the last 48 years produced greater than 10 cm of precipitation in a 24 hour period. The large precipitation events resulted from a convective storm in July 1984 and from two frontal storms occurring in December 2004 and February 1988.

There have been four frontal storm events subsequent to the June 2005 fire that produced greater than 2 cm of precipitation within a 24 hour period (Figure 31). Field work completed after the most recent frontal storm to produce at least 2 cm of

precipitation (July 2006) identified locations where sediment had been mobilized on the burned hillslope. Soil pits on the burned yucca-blackbrush hillslopes had been partially filled back in and fresh looking sediment deposits were observed on the upslope side of piñon and juniper trees on the burned piñon-juniper hillslopes. The only area in which sediment was mobilized from these hillslope was a small fan formed on a remnant terrace at the base of the yucca-blackbrush hillslope. Measurements of sediment depth above the burn etch line on the small fan indicated approximately 10 cm of post-fire sediment deposition had occurred following the 2005 fire.

Probability of storm occurrences dropping specific amounts of precipitation were created using the Western Regional Climate Center's (WRCC) website (Figure 32). The probability graphs indicate that the highest probability of precipitation events occurs

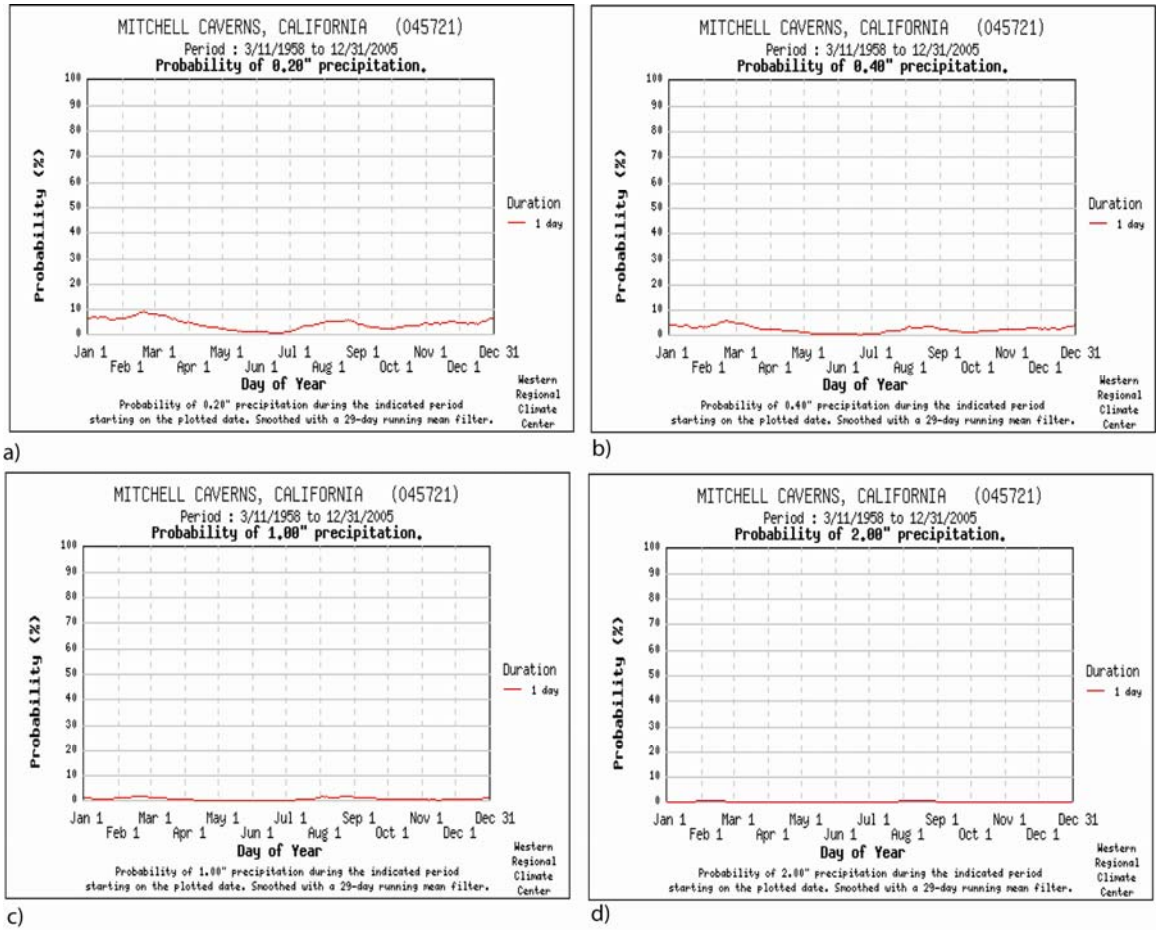

Figure 32. Probability of precipitation events occurring throughout the year, provided by the Western Regional Climate Center (WRCC). a) probability of a storm producing 0.5 cm of precipitation throughout the year, b) probability of a storm producing 1 cm precipitation throughout the year, c) probability of a storm producing 2.5 cm precipitation throughout the year, and d) probability of a storm producing 5 cm precipitation throughout the year.

between, January through March, and July through September. Even during periods when precipitation is most likely to occur the probability of 0.5 cm of precipitation falling on any given day is never greater than 10%. The probability of a storm event producing 2.5 cm of precipitation in a day is exceedingly rare, out of 17,365 measurements collected at the Mitchell Caverns weather station only 124, an average of two events a year, have exceeded rainfall of 2.5 cm over a 24 hour period. During

months associated with the highest likelihood of precipitation events the probability of a storm event producing 5 cm of precipitation a day is less than 1% (Figure 32).

5. Discussion

5.1 Impact of particle size and vegetation litter on infiltration and erosion rates of soils

Coarse grained soils have been shown to have increased rates of infiltration compared to soils with higher silt and clay content (Cereda, 1997; Casanova et al., 2000). Post-fire erosion resulting in alteration of particle size distribution may affect the infiltration rates of soils. Initial effects of erosion have been shown to result in loss of fine-grained sediments in the horizons closest to the surface, which can result in increased infiltration rates. Hillslope soils in the Mid Hills region have approximately less than 20% fines (whole soil sample) in the A-horizons of all soil profiles (Table 7 and 8). Particle size data results indicate that post-fire sediment mobilization and erosional events have minimal affect on the overall particle size distribution of hillslope soils (Figure 27). The relatively homogeneous particle size distribution on pre- and post-fire soils (Tables 5 and 7), indicates that infiltration rates of the soils are not significantly affected by post-fire redistribution of sediment. The whole soil particle size composition in the A-horizon of all soil pits does not appear to vary enough to cause significant changes in infiltration rates of any of the soils. Other factors which may affect infiltration rates include root structures and organic matter content in the C/O- and A-horizons.

The open interspace regions on the hillslopes are thought to be more susceptible to erosional processes than surfaces better protected below vegetative canopies. If substantial preferential loss of sediment had been occurring in the soils located in the interspace areas, there should be a stronger variation in particle size distribution between the canopy and interspace soil pits. Particle size data from canopy and interspace regions did not identify preferential sediment loss in interspace regions compared to the canopy soils. Initial results from Cs-137 data indicate that the top 5 cm of both the side slope and interspace regions tend to accumulate sediment. Cs-137 data did not indicate considerable loss of sediment in the interspace regions compared to the side slope regions of soil pits in either ecotone.

Previous studies have shown that a high percentage of plant cover and large amounts of root biomass and plant litter can result in more rapid infiltration rates for a given location (Rauzi et al. 1968, Meeuwig, 1970; Blackburn, 1975; Berndttsson and Larson, 1987). There is substantial vegetative cover in the Mojave National Preserve, especially on semi-arid hillslopes in higher elevations such as the Mid Hills region of the Mojave National Preserve. There was considerable fine organic matter content (based on LOI data) on the interspace and canopy surfaces on all four hillslopes, burned and unburned. The reason for this is likely two-fold: (1) there is considerable amounts of vegetation on these hillslopes producing litter which breaks down into fine organic matter, and (2) in such an arid region the surface litter maintains its structure for a longer period of time. Fine organic matter content increased on the surface of the burned yucca-blackbrush hillslope relative to the unburned yucca-blackbrush hillslope. It is likely that the fire was not intense enough to destroy the fine organic matter on the surface. Instead,

ash from the fire deposited on the hillslopes appears to have added increased fine organic matter content on to the surface around the burned vegetation. Increased fine organic matter on the surface below the canopy of the burned yucca-blackbrush hillslope may explain the increased infiltration rates at both supply pressure heads (-4 and -1 cm) on the burned upslope regions of the yucca-blackbrush hillslope (4.6 cm/hr and 9.6 cm/hr) compared to the unburned upslope regions of the yucca-black brush hillslope (2.8 cm/hr and 6.7 cm/hr) (Casanova et al., 2000 and Wilcox et. al, 2003).

Infiltration tests run at the slower supply pressure head (-4 cm) found that upslope and interspace regions of all four hillslopes, had a minimum infiltration rate greater than 2.5 cm/hr at the given supply pressure head. Such rapid infiltration even on the burned hillslopes indicates that fire in such arid regions has very limited impact on soil properties which effect runoff and infiltration rates on these semi-arid hillslopes.

Results of infiltration experiments must be carefully interpreted. Infiltrometers are useful field instruments because of their small size and easy set up, however when evaluating data many things must be considered, such as: (1) the data attained is on a very localized surface compared to the overall environment, (2) the surface must be slightly disturbed to create a level pad for the infiltrometer to sit, (3) any localized heterogeneity may significantly alter results, and the infiltration process is measured by a potential condition, which is determined by the tension applied. Infiltration rates calculated by tensiometer experiments are indicative of trends within a very localized area; scaling infiltration results to hillslope or basin wide trends can result in infiltration rates that do not account for the heterogeneity of the soils. A key finding in this study was the uniform particle size distribution throughout the horizons, this seemingly

indicates that the infiltration rates calculated for the interspace and upslope regions of the hillslopes are indicative of wider hillslope trends.

By incorporating the various aspects of the hillslope properties and infiltration data with known precipitation trends in the region, it seems that it would take an exceedingly rare storm, >2.5 cm/hr, to create runoff on these hillslopes. Based simply on the calculated infiltration rates a storm event which produces enough precipitation to create runoff is practically non-existent in the Mid Hills region. It is important to note that antecedent moisture content of soil, frozen soil, along with other factors also influence infiltration rates. Very few historic precipitation events have been recorded that are likely to produce surface runoff across the entire slope.

5.2 Fire is not a significant geomorphic agent on hillslopes in semi-arid regions

The 2005 fire was not the catalyst for formation of all the rills observed on the burned hillslopes. Both burned hillslopes had evidence of recently active rills, but analysis of hillslope transects incorporating rills and disturbed surfaces showed that many of the rills and low points along the transects were present prior to the 2005 fire (Figures 19 and 21). Rills present prior to 2005 were potentially reactivated, widened, deepened, and even propagated further upslope during post-fire precipitation events. Even though rills were reactivated and further eroded, the mouth of the rills lacked any substantial post-fire sediment deposition. Post-fire precipitation events did not appear to significantly affect hillslope stability on either of the burned hillslopes. Mobilization of sediment from the hillslopes was only noted in one location, on a remnant terrace at the base of the burned yucca-blackbrush hillslope.

The burned yucca-blackbrush hillslope initially appeared to have undergone substantial localized mobilization of sediment on the surface, but pre-fire surface topography indicates that significant rill formation and topographic variation was already present on the surface prior to the 2005 fire (Figures 20 and 21). Rills on the burned yucca-blackbrush hillslope did not experience the level of down cutting that was observed on rills on the burned piñon-juniper hillslope (Figures 19 and 21). The yucca-blackbrush hillslope has substantially more overall vegetation than the piñon-juniper hillslope, the increased vegetative cover likely breaks up sheet flow and creates the mini-rills, observed around some of the plant mounds, and prohibits the deep down cutting of rills that was observed on the piñon-juniper hillslope. The piñon-juniper hillslopes lack the vegetation necessary to break up sheet flow, enhancing the sheet flow and causing down cutting of pre-existing rills. The function of sediment thickness and corresponding rill depth is unclear. Sediment on the burned yucca-blackbrush hillslope, which had shallower rills than the burned piñon-juniper hillslope, was on average twice as thick as the sediment on the burned piñon-juniper hillslope (Table 6).

No fires have occurred on these hillslopes since historical records have been kept for the area beginning around 1958. Soils exposed on both burned hillslopes did not identify any evidence of previous fires. These results indicate that rills formed prior to the 2005 fire may have resulted from causes other than fire.

Post-fire sediment movement on the hillslopes resulting in the formation of sediment mounds on the upslope side of vegetation appeared to occur on a much larger scale on the piñon-juniper hillslopes than on the yucca-blackbrush hillslopes. On the burned piñon-juniper hillslope approximately 12 cm of sediment accumulated above the

burn etch lines on the upslope side of the trees indicating substantial post-fire sediment deposition (Figure 23). Burned yucca-blackbrush stalks had approximately 1 cm of sediment deposition above the burn etch line on the upslope side of the stalks (Figure 23). The overall heights of the mounds were smaller on the burned and unburned yucca-blackbrush hillslopes compared to the burned and unburned piñon-juniper hillslopes (Figure 22). This also may be correlated to less overall vegetative coverage on the piñon-juniper hillslopes than the yucca-blackbrush hillslopes. Hillslopes with greater amounts of vegetative cover potentially have smaller sediment mounds dispersed over more plants.

6. Summary

Previous work in the Mojave National Preserve identified poorly vegetated hillslopes in semi-arid basins that had uniform soil coverage and were stable with minimal signs of recent surface erosion (Chapter II). These findings resulted in questions regarding how hillslopes in semi-arid regions respond to the effects of environmental change, such as fire, which alters the vegetative coverage of the hillslope surface (Chapter III). Field work completed one year after a fire that burned 284 km^2 in the Mojave National Preserve indicates that there was no large scale loss of sediment from the burned hillslopes. Following the 2005 fire there have been four storm events that produced greater than 2 cm of precipitation over a 24 hour period. The most recent storm events occurred in July 2006; fieldwork completed shortly after this storm event found fine-grained particles had been locally mobilized on the burned yucca-blackbrush hillslope partially filling in soil pits that had been left open. Hillslope sediment

mobilization was only observed in one localized area at the base of the yucca-blackbrush hillslope. Sediment removed from the hillslope had formed a small fan deposit on a remnant terrace at the toe of the hillslope. It was not possible to distinguish how much of the mobilized hillslope sediment was from the July precipitation event versus the other three significant post-fire precipitation events. Sediment approximately 10 cm thick had been deposited post-fire over the entire 3 x 5 m area, forming a small fan-like deposit

Vegetation loss due to fire appears to have had an insignificant effect on the hillslope stability of the burned field sites. Pre-fire rills were apparent on many of the hillslopes indicating that rill formation is not dictated by the loss of vegetation due to fire, although rills may be reactivated after a fire and may potentially form post-fire.

Results from this fieldwork identified homogenous soil properties (i.e. degree of soil profile development, particle size distribution, and fine organic matter) across the burned and unburned hillslopes and within the two different ecotones, indicating that fire on these hillslopes has minimal impact on soil properties and erosion rates in the semi-arid region of the Mojave Desert. This contradicts the commonly held belief that fire resulting in vegetation loss is correlated to post-fire rill formation on hillslopes and increased mobilization and removal of sediment from hillslopes.

7. Conclusions

Erosional features, such as rills, commonly assumed to rapidly form post-fire, were proven to be present on the hillslopes prior to the 2005 fire. Only one localized area of post-fire sediment mobilization off the hillslopes was identified. These findings compliment other recent research on fire and hillslopes, which have found evidence that

burned hillslopes, in arid to semi-arid regions, do not necessarily result in sediment loss (Carcaillet et al., 2006; Yang et al., 2006; Germanoski and Miller, 1995).

No considerable change in infiltration rates was noted on the burned hillslopes compared to the unburned hillslopes indicating the fire lacked the intensity necessary to significantly affect soil properties and create a hydrophobic layer on the hillslopes. Calculated hillslope infiltration rates combined with 48 years of climate data indicate that storm events large enough to generate surface sheet flow and possibly erosion on the hillslopes are rare. This and other recent research indicates many factors must commence at one time to provide the parameters necessary to substantially mobilize sediment off hillslopes (Carcaillet et al., 2006; Yang et al., 2006).

Findings from this study are similar to results of Yang et al.'s (2006) work, which showed that rills did not form easily even under very intense precipitation on relatively steep hillslope plots that were stripped of vegetation. Yang et al. (2006) found that once rills were created (manually) at the base of the plots the rills began to propagate upslope, the upper part of the rills remained shallower than the upper portion of pre-existing rills. Both the burned piñon-juniper and burned yucca-blackbrush hillslope had rills that formed at the base of the hillslope pre-fire, moving upslope the rills become shallower and less defined, the upper part of the rills likely propagated uphill during post-fire precipitation events.

Measurements of erosional features on burned hillslopes identified localized mobilization of sediment on hillslopes, but no macro-scale geomorphic disturbances were identified. Measurement of the sediment mounds on the upslope sides of the vegetation on both hillslopes indicated post-fire transport of sediment occurred on the hillslopes, but,

generally, sediment was not mobilized from the hillslopes. High content of fine organic matter in the C/O horizon is further evidence that the surface horizon has been moving down slope, mixing fine organic matter from the A-horizon into the gravel layer. Mobilization of sediment on the hillslopes but not removed from the hillslopes indicates that fire affects the hillslopes on a localized scale, with no immediate impact on the overall hillslope stability. After 0.1 ky or even 1 ky many localized sediment mobilization events may result in macro-scale hillslope erosion. Multiple localized events would have to be observed to support this hypothesis.

General observations of second order channels in the general location of the field site identified significant sediment being flushed out of relatively small channels resulting in the formation of alluvial fans, which were cut by the main drainage. It appeared that these alluvial fans had been forming through multiple sedimentation events over many hundreds of years. Some of the fans have what appear to be recent sediment deposits potentially related to post-fire sediment mobilization. A detailed study of these geomorphic landforms was outside the scope of this study, but initial observations support Germanoski and Miller's (1995) findings that post-fire sediment mobilization is a process that is limited primarily to axial channels and does not significantly affect hillslope processes.

Conclusions from this research challenge traditional assumptions regarding hillslope erosional processes. It appears that fire resulting in vegetation loss is not a strong geomorphic force on semi-arid hillslopes in the Mojave Desert. This work combined with future work can assist in addressing fire mitigation practices in semi-arid

regions and also serves as an indicator of the severity of erosion that can be expected on burned hillslopes during periods of normal annual rainfall.

Chapter IV – Stability of hillslopes and uniformity of formation of geomorphic landforms in semi-arid regions

1. General Summary

The principal objectives of this research were to identify the specific impacts of Holocene climate change and recent fire events on hillslopes and landform development in semi-arid regions. Knowledge attained by studying past and present impacts of environmental change on geomorphic activity allows for predictions to be made on future geomorphic events.

Production, storage, and transport of sediment during periods of Holocene climate change

Studying Holocene sediment production, transport, and stability in semi-arid basins and comparing knowledge attained from landform soil profiles to previously dated soil profiles on the Providence Mountains piedmont allowed for a better understanding of geomorphic processes occurring in semi-arid regions. Research in the basins, discussed in Chapter II, identified four key results:

(1) Based on comparison of the degree of soil development on key landforms in the basins to soil development on alluvial fans, it was found that soils present on the surface of landforms in the basins are all late Holocene in age. Alluvial fans in the region date back to the early Pleistocene, so it was very surprising to find such young soils throughout both basins. The lack of older soils in the basins implies that the older soils have been completely covered by younger sediment or removed from the basins during intense precipitation events.

(2) Soil development on landforms within the basin identified two distinct soil ages. Based on the degree of soil development hillslope soils were estimated to be less than 1 ka, where as the soils developed on colluvial aprons and the Qft1 fan-terrace were shown to be approximately 4 ka. These two distinct ages of soils, indicate at least two periods of significant change in environmental conditions over the last 4 ky.

(3) Significant eolian derived silt and fine-grained particles were identified in both basins. Hillslope soils in both basins had the greatest accumulation of fine-grained particles. XRF analysis was completed on fines, sand, and bedrock samples from both basins, results showed that the fine-grained sediment in both basins was derived from a similar external source. The significant amount of fine-grained particles in both basins indicates that during the geologic past there were significant sources of fine-grained particles that were exposed and susceptible to wind erosion.

(4) Sediment in both basins appears to accumulate on hillslopes and than be transported onto the basin floor where the sediment is stored in terraces. Sediment deposited on the terraces is than transported out of the basins and on to the Providence Mountain piedmont forming an alluvial fan or covered by new hillslope derived sediment.

Effect of fire on hillslope sediment loss in the semi-arid Mojave Desert

Elucidating the relationship between vegetation loss, formation of erosional features, and loss of sediment on hillslopes, has significant impacts on the way hillslope stability is perceived during post-fire events. Fieldwork and data analysis from the Mid Hills field site, Chapter III, led to three main conclusions:

(1) Changes in vegetative cover by themselves do not control sediment removal from hillslopes. Fieldwork completed after one year of convective and frontal storms passed over the hillslopes only identified one location where sediment had been transported from the hillslope. The lack of post-fire sediment mobilization from hillslopes suggests that loss of vegetation on hillslopes does not result in any immediate macro-scale geomorphic changes.

(2) Rill formation is not limited to post-fire activity. Pre- and post-fire surface indicators provide evidence that some percentage of the rills were present pre-fire and experienced post-fire activity. Post-fire activity included down cutting of rills and in some cases propagating rills upslope. The mouths of the rills did not have evidence of post-fire sediment movement indicating post-fire reactivation of rills did not result in movement of sediment from the hillslopes.

(3) Strong evidence of localized sediment on both burned hillslopes was observed. Sediment mounds measured on the upslope side of vegetation on all four hillslopes found that the mounds were larger on both the burned and unburned piñon-juniper hillslopes compared to the yucca-blackbrush hillslopes. On a localized scale differences in mound height on slopes in each ecotone likely illustrates the impact of vegetation on sediment distribution on hillslopes. The yucca-blackbrush hillslopes have greater vegetative coverage, which helps breaks up sheet flow, and also results in smaller mounds distributed over a larger area, so it appears that less sediment has been mobilized on the yucca-blackbrush hillslopes than the piñon-juniper hillslopes.

2. General Conclusions

The combination of both studies advances the knowledge of processes affecting hillslope stability and formation of landforms in semi-arid regions. Results challenge some long held assumptions regarding the role of vegetative coverage and fire on hillslope stability. Many of these previous assumptions were based on observations conducted on a macro-scale level with minimal emphasis on local hillslope processes. Results from this study conclude that hillslope sediment in semi-arid regions is much more resistant to erosional processes under current climatic conditions than previously believed. Paleoclimate events resulted in significant and sudden sediment mobilization from hillslopes onto the surfaces below forming colluvial aprons and fan-terraces within the basins. Soils on the hillslopes were very young (<1 ka based on the degree of soil development) implying there have been episodic sediment mobilizing events on the hillslopes up until ~1 ka. Hillslopes have been stable over the last ~1 ka, accumulating significant amounts of eolian derived sediment. The second study, which focused on burned and unburned hillslopes, and the impact of the loss of vegetative cover, also found hillslopes were more stable than commonly assumed even after substantial loss of vegetative cover due to fire. Both studies help elucidate geomorphic processes in semi-arid regions and provide some new and interesting background for further studies to build upon.

What Next?

The abundance of eolian derived sediment accumulation on hillslopes in the Providence Mountain range was a surprising find. Further research elucidating the origin

of the fine-grained sediment and the breadth of the eolian deposition within the Providence Mountain range would serve as a very interesting indicator of the paleoenvironment and paleoclimate activity of the Providence Mountains.

Homogeneity of soil cover identified on hillslopes in both the Mid Hills region and the Providence Mountain basins indicates that these locations are likely excellent regions to run infiltrometer tests. The homogeneity of soils from the infiltration tests can be more reliably scaled up to basin size infiltration trends. Further infiltration studies in semi-arid regions with similar homogenous soil trends completed during times of annual changes in precipitation patterns would greatly increase the knowledge of runoff and infiltration rates in semi-arid regions.

A negative correlation between mound height and vegetative cover was noticed in the Mid Hills region. Results indicate that increased vegetation on hillslopes results in smaller mounds and hillslopes with smaller mounds have less significant post-fire movement of sediment on hillslopes. A more detailed study of this process would assist in better understanding localized post-fire sediment mobilization on hillslopes.

Portions of rills were shown to have formed on the hillslopes pre-fire. Although significant rill activation was observed on the burned hillslopes this may be associated with less vegetation covering the rills and reactivation of the rills, giving the rills a “fresh” look, which is why so often rill formation is associated directly to a fire or other intense event, which results in some obvious change, such as a decrease in vegetation. Measurements indicate that rills were reactivated post-fire, some rill down cutting occurred and some rills were propagated up slope, but no significant sediment was mobilized by the rills during post-fire precipitation events. This is a key finding in

understanding post-fire erosional processes and more research must be done to better understand the relationship between vegetation loss, fire, and rill formation. Studying rill formation in natural settings could be done without using a burn area. Simply identifying rills on hillslopes and placing semi-permanent soil baseline indicators and transect lines on the hillslopes and measuring changes in base line soil level and height of ground to the transect line after each storm event greater than 2 cm in the Mojave Desert would greatly advance the knowledge of rill formation and erosional processes on hillslopes in semi-arid regions.

This research was built off the extensive knowledge gained from previous studies of soils developed on landforms, erosional patterns on hillslopes, and the affect of paleoclimate change on vegetative cover, soil development, and weather patterns. Knowledge attained from this research increases the scientific knowledge of geomorphic processes affecting basins and hillslopes while also offering new directions of exploration for future studies in order to increase our knowledge of geomorphic processes in arid basins.

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Appendices

Important note regarding appendices:

***** All abbreviations used when describing soils samples are from Birkeland, 1999 and from the National Soil Survey Staff, 2003, Keys to Soil Taxonomy. *****

Appendix 1 – Field Soil Descriptions for the Providence Mountains

Soil Profile Morphology

Location: Granite Basin
Fountain Peak, CA, Quad

Landform: colluvial fan apron
Field ID: GB-3
Lab ID: 06-1736 - 06-1740
Date Described: 10/05/05
Vegetation: Mojave Desert Scrub
Slope Aspect: S facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
AB	10	10 YR 6/3	10 YR 3/2	l	1m+f, sbk	dsh-so, mfr	1-2 vf	1-2 vf t	bot: pat f sil co	5-15 vf>3 0>5	cs	none	none
Bw	29	10 YR 5/3	10 YR 3/3	l	1m+f, sbk	dsh, mfr	1-2 vf, vfm	1 vf t	bot: pat f sil co	10-20 f>3 vf>5	cs	none	bot: v pat f f co
2Bw	57	10YR 5/4	10 YR 4/3	l	1 m sbk, 2 m	dsh, mfr	1vf,m	1vf t	bot: pat f sil co	20-35 f>5 c>3	cw	none	bot: v pat f f co
BC	80	10 YR 5/3	10 YR 3/3	l	m, 1 m, sbk	dsh-so, mfr-vfr	1f	vf, vf t	none	20-35 f>5 c>3	cs	none	bot: v pat f f co
C	104+	10 YR 5/3	10 YR 3/3	l	m	dso,mfr	1f	1 vf t	none	50-70 m>3 c-m>5	n/a	none	bot: pat f f co

Additional Notes: The prescence of carbonate described in this morphology was likely, an evaporite, based on the lack of observable effervescence on any of the surfaces.

Soil Profile Morphology

Location: Granite Basin
Fountain Peak, CA, Quad

Landform: colluvial fan apron
Field ID: GB-4
Lab ID: 06-831 - 06-836
Date Described: 10/05/05
Vegetation: Mojave Desert Scrub
Slope Aspect: SE facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
A	3	10 YR 5/3	10 YR 3/2	l	crb, 1m+pl in places	dso-dsh	2 vf	1-2 vf i+t	none	5-15 0>5 vf>3	as	none	
AC	11	10 YR 5/3	10 YR 3/3	ls	sg-m	dlo-so, mlo-vfr	1-2 vf	1-2 vf i	v pat f sil co	20-40 0>5 F>3	af	none	bot: v pat f f co
Ab	20	10 YR 6/4	10 YR 4/3	l	1-2 m+f, sbk	dso-dsh, mvf-mfr	1-2 vf, 1f+m	1-2 vft	pat sil co	15-25 f>3 vf>5	cs	none	none
Bwkb	59	10 YR 5/4	10 YR 3/4	l	1m+f, sbk-m	dsh-dso	1-2 vf, 1f+m	1 vf t + 1m t	pat f sil co	25-45 c-f>5 c-m>3	cs	none	bot: pat f-d co
BCb	80	10 YR 5/4	10 YR 4/3	sl	m+sg	sh-lo mfr-lo	1 f	1 vf + m t	none	20-40 f>5 c>3	cs	none	bot: v pat f f co
C	97+	10 YR 5/4	10 YR 4/3	l-sl	sg	dso-lo-mvfr-mo	1 f	none	none	40-60	n/a	none	bot: v pat f f co

Additional Notes: The prescence of carbonate described in this morphology was likely, an evaporite, based on the lack of observable effervescence on any of the surfaces.

Appendix 1 – Field Soil Descriptions for the Providence Mountains cont'd

Soil Profile Morphology

Location: Granite Basin
Fountain Peak, CA, Quad

Landform: colluvial fan apron
Field ID: GB-8
Lab ID: 06-837 - 06-841
Date Described: 10/05/05
Vegetation: Mojave Desert Scrub
Slope Aspect: N facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
A	3	10 YR 4/3	10 YR 3/3	l	1-2 m, crb+sbk	dso	2-3 vf	1-2 vf i	v pat sil co	10-20 vf>3 0>5	as	none	none
AB	14	10 YR 5/4	10 YR 3/3	l	1m + f, sbk	dsh, mfr	2vf-1 f	2vf t+I 1f t	pat sil co	15-35 f>3 f>5	cs	none	none
Bw	38	10 YR 4/3	10 YR 3/2	l	1-2 m+f, sbk	dsh, mfr	1-2 vf, 1 f	2vf i +t 1f t	pat f co	20-40 f>3 f>5	cs	none	none
CB	61	10 YR 4/4	10 YR 4/3	l	m	dsh-dso	m	1 vf t + i	none	40-60 c>3 f>5	cw	none	none
Ck	82+	10 YR 4/6	10 YR 3/4	l	sg-m	m	sg-m	1 vf i (?)	none	50-70 c>5 m>3	n/a	none	bot: pat f-df co (in fractures)

Additional Notes: The prescence of carbonate described in this morphology was likely, an evaporite, based on the lack of observable effervescence on any of the surfaces.

Soil Profile Morphology

Location: Granite Basin
Fountain Peak, CA, Quad

Landform: colluvial fan apron
Field ID: GB-20 (GB-11)
Lab ID: 06-842 - 06-846
Date Described: 10/05/05
Vegetation: Mojave Desert Scrub
Elevation:
Slope Aspect: 0-1º N/W facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
A	2.5	10 YR 5/4	10 YR 3/2	l	1 t, m pl -> 1 f , vf sbk	dso-dsh, m v fr	3-2 vf	1 vf t	pat ft sil spots	10-20	as	none	none
AB	7.5	10 YR 4/3	10 YR 3/3	l	1 m, m+f, sbk	dsh,mfr, wso-ss, wps	1-2 vf	1 vf t	pat ft sil spots on bots	10-20 vf>5 f-vf>3	cs	none	none
Bwk	28	10 YR 4/6	10 YR 3/3	l	1-2 m,f, sbk	dsh,mfr, wso, wps	2-1 vf, 1-2 m+f	1-2 vf + ft	pat ft sil br +co	15-25 f>3 vf>5	cw	none	bot: vf pat-pat f-df co + fs
BCk	58.5	10 YR 5/4	10 YR 3/4	sl	sg +1 m, sbk in places	dlo-so, mmlo-vfr, wso,wvps	1-2 vf + m	1 f + f t in in places	none	45-65 c-m>3 f-c>5	cs	none	bot: vf pat - pat f f co
Ck	94+	10 YR 6/3	10 YR 4/3	sl-ls	none sg	dlo, mlo, wso, wpf	1vf -f	1 vfi + t	none	55-75 c-m>5	none	none	bot: vf pat - pat f f co

Additional Notes: The prescence of carbonate described in this morphology was likely, an evaporite, based on the lack of observable effervescence on any of the surfaces.

Appendix 1 – Field Soil Descriptions for the Providence Mountains cont'd

Soil Profile Morphology

Location: Winston Basin
Fountain Peak, CA, Quad

Landform: fan-terrace
Field ID: WB-7
Lab ID: 06-1741-06-1745
Date Described: 10/06/05
Vegetation: Mojave Desert Scrub
Slope Aspect: 0-1º N/W facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
A	2	10 YR 5/2	10 YR 4/2	l	1-2 m, crb	dso	2vf	1-2 vf i +t	none	15-25 vf>3 0>5	as	none	none
AC	9	10 YR 4/4	10 YR 3/3	sl	m	dso	1-2 vf	2 vf + f i+t	none	20-40 vf>3 0>5	cs	none	none
C	22	n.m.	n.m.	ls	m	dso	1 vf	2 vf i	none	20-4- vf>3 0>5	cs	none	none
1Ck	66	10 YR 5/3	10 YR 3/4	ls	m-sg	dso-lo	1 vf - vf m	2vf I, 1 f i	none	25-55 f>3 vf>5	cs	none	bot: pat f - d f co
2Ck	82+	10 YR 5/4	10 YR 3/3	ls-s	sg (cobble peb.)	dso-lo	vf m + f	none	none	50-70 m>3 m>5	n/a	none	bot: pat -nc f-d f co

Additional Notes: The prescence of carbonate described in this morphology was likely, an evaporite, based on the lack of observable effervescence on any of the surfaces.

Soil Profile Morphology

Location: Winston Basin
Fountain Peak, CA, Quad

Landform: fan-terrace
Field ID: WB-8
Lab ID: 06-1746-06-1751
Date Described: 10/06/05
Vegetation: Mojave Desert Scrub
Slope Aspect: 0-1º N/W facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
A	2	10 YR 5/4	10 YR 4/3	l	1-2 m+f, crb	dso, mvfr	2 vf	1-2 vf t	v pat fsil co	10-20 0>5 f>3	as	none	none
AB	8	10 YR 5/3	10 YR 4/3	l	1 t + m pl -> 1 m+f, sbk crb	dso, mvfr	2 vf	2 vf t+i	pat f sil co	10-20 f>3 0>5	as	none	none
Bw	30	10 YR 5/3	10 YR 4/3	sil	1-2 m+f, sbk	dsh	1 vf, 1 f, vf m	2 vf t+i+1 ft	pat sil co	15-30 f>3 0>5	cs	none	none
2Bwk	51	10 YR 5/3	10 YR 4/3	l	1 m, sbk, 2 m	dsh-dso	1 vf, 1 f, vf m	2-1 vf i	pat f sil co	15-30 f>3 0>5	cs	none	bot: pat df co
Ck	76	10 YR 5/3	10 YR 3/4	sl	sg-m	dlo-dso	1 vf, f	2-1 vf i	none	40-60 f-c>3 f>5	cs	none	bot: pat-nc f co
Ck2	102+	10 YR 4/6	10 YR 4/3	ls	sg-m	dlo-dso	1 vf, f	2-1 vf i	none	40-60 f-c>3 f>5	n/a	none	bot: nc-pat d f co

Additional Notes: The prescence of carbonate described in this morphology was likely, an evaporite, based on the lack of observable effervescence on any of the surfaces.

Appendix 1 – Field Soil Descriptions for the Providence Mountains cont'd

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: colluvial wedge
Field ID: Pit#1a
Lab ID: 06-2444 - 06-2447
Date Described: 05/19/06
Vegetation: low desert shrubs, yucca
Slope Aspect: 0-1º N/W facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Avj	4	2.5Y 6/3	2.5Y 4/3		1 m sbk	dsh-dso	1 - 2 vf	1-2 vf i+v	pat sil bots	10-20 f-c>3 f>5	as		bot: pat co-f f co
Bwk	24	2.5Y 6/3	2.5Y 4/3		1-2 m-sbk	dso-dsh	1-2 vf t, 1ft	1-2 vf, 1f	none	10-20 f-c>3 f>5	cs		bot: nc-pat d f co
BCk1	51	2.5Y 6/3	2.5Y 5/3		sg	dlo	1 vf f	1vf t	pat. sil co	25-50 c>5 c-m>3	cs		bot: nc p-d f co
BCk2	99+	10YR/2.5 Y 7/3	10YR 5/4		sg	dlo	1 vf, 1f	1vf t	none	60-80 m>5	n/a		bot: nc p-d f co

Additional Notes: Looking down drainage there is increasing carbonate coating on clasts w/depth. Some carbonate coated clasts in Unit BCk2 appear to have been reworked.

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: colluvial wedge
Field ID: Pit#1b
Lab ID: 06-2448 - 06-2451
Date Described: 05/19/06
Vegetation: low desert shrubs, yucca
Slope Aspect: 0-1º N/W facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Av	4	2.5Y 6/3	10YR/2.5 4/3		1 m pl + 1 m sbk	dsh-dso	1-2 df	1-2 vf t, 1 v in places		10-20 f>5 c-f>3	as		bot: pat f f co top: pat f f co
Bwk	22	2.5 Y6/3	10YR/2.5Y 4/3		1 - 2 m sbk	dso-dsh	2 vf t , 1 f t	1 vf t	top: pat sil	25-45 c-f>3 f>5	cs		bot: nc d-f f co
BCk1	39	2.5 Y 6/3	10YR/2.5 Y 4/3		sg+	dlo	1-2 vf, 1 f	1-2 vf i + t		25-45 c-m>3 f-c>5	cs		bot: nc d-f f co top: pat f f co
BCk2	63+	2.5 Y 6/3	10YR 4/3		sg	dlo	1 vf + f	1 vf i, 1 f i		50-70 m-c>3 c>5	n/a		bot: nc pat v f f f co top: pat f f co

Additional Notes: This is a colluvial wedge like deposit, older than pit #1a.

Appendix 1 – Field Soil Descriptions for the Providence Mountains cont'd

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: fan-terrace
Field ID: Pit#9
Lab ID: 06-2470 - 06-2476
Date Described: 05/19/06
Vegetation: creosote, acacia
Slope Aspect: N-facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Av	3	2.5Y 6/3	2.5Y 4/2		1 m pl + 1-2 m sbk	dso	1-2 vf	1-2 vf, v+i	pat sil co	10-20 f>3 vf>5	as		none
Bwk	15	10Y 6/3	2.5Y 4/2		1-2 m sbk	dsh-dso	2-3 vf, 1 f	1-2 vf t, 1 f t	pat si co	15-30 c>3 f-c>5	cs		bot: nc f f co
Bk	40	2.5Y 5/2	2.5Y 3/2		sg	dlo	1-2 vf, 1 f	2 vf i, 1 f i	none	40-60 m-c>3 c>5	c-ds		bot: nc p-d f-m co top: nc f f co
BCk	56	2.5Y 5/3	2.5Y 4/3		sg	dlo	1-2 vf, vf f	1-2 vf i + t	none	45-65 m>3 c-m>5	cs		bot: nc d-f f co pow.+ cw mat. top: v pat f f co
CBk	84	2.5Y 6/3	2.5Y 4/3		sg	dlo	1-2 vf i, 1 vf i	1-2 vf i, 1 vf i	none	55-75 m>3 c-m>5	cs		bot: pat d-f co top: v pat f f co
Ck1	104	10 YR 5/2	10 YR 3/2		sg	dlo	1 m i, 2 vf i + i	1 m I, 2 vf i + i	none	55-75 m<3 c-m>5	cs		bot: pat d-f f co top: none
CK2	114+	10 YR 5/3	10 YR 3/3		sg	dlo	2 vf i, 1 m i	2 vf i, 1 f I, 1 m i	none	60-80 m>3 m>5	n/a		bot: pat f f co, cw mat. top: none

Additional Notes: clasts present throughout the sample are very angular

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: fan-terrace
Field ID: Pit#5
Lab ID: 06-2452 - 06-2454
Date Described: 05/19/06
Vegetation: creosote, acacia
Slope Aspect: N-facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Av	3	10 YR 5/3	10 YR 3/3		1 m + f sbk 1 m pl	dso	1 vf	1-2 vf v+t	bot: pat si co top: si co	10-20 f>3 vf>5	as		none
Bwk	28	10 YR 5/3	10 YR 4/3		2-1 m sbk	dsh-dso	1-2 vf	1-2 vf t	top: pat si co	15-30 c-f>3 f>5	cs		bot: nc f f co
Bk	62+	10 YR 6/3	10 YR 4/3										

Additional Notes: This is representative of the top half pf pit #9 in a less disturbed area. There is much more silt in Pit #5 compared to Pit #9. This could be the result of debris flow in the vicinity of Pit #5 influencing the silt content.

Appendix 1 – Field Soil Descriptions for the Providence Mountains cont'd

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: fan
Field ID: Pit#6
Lab ID: 06-2455 - 06-2459
Date Described: 05/19/06
Vegetation: creosote, acacia
Slope Aspect: N-facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Avj	2	10 YR 5/3	10 YR 3/2		1 m sbk	dsh	1-2 vf	1-2 vf t + v		20-40 c>3 f-c>5	as-aw		bot: pat f f co
Cak	26	10 YR 6/2	10 YR 4/2		sg	dlo	1-2 vf	1-2 vf i		50-70 m>3 c-m>5	cs		bot: pat f f co top: none
Ck1	56	10 YR 6/2	10 YR 4/2		sg	dlo	1 vf; vf m	1-2 vf i		45-65 m>3 c-m>5	ds		bot: nc pat f-d f co top: none
Ck2	84	10 YR 6/3	10 YR 4/3		sg	dlo	1-2 vf, 1 vf in pockets	1-2 vf i		45-55	cs		bot: pat f f co top: none
Ck3	99+	10 YR 6/2	10 YR 4/2		sg	dlo	1-2 vf	1-2 vf i		35-55 c>3 c>5	n/a		bot: pat f co top: none

Additional Notes:

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: Colluvial deposit
Field ID: Pit#7
Lab ID: 06-2460 - 06-2463
Date Described: 05/18/06
Vegetation: creosote, yucca, barrel cacti
Slope Aspect: S-facing

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Avj	3	2.5Y 6/3	2.5Y 5/3		1-2 m pl + 1 m sbk	sh	1 vf	1 vf t, f v	none	15-30 c>3 f>5	as		bot: pat f f co
Bwk (AC)	18	10YR 6/4	10YR 4/3		sg+ 1 m sbk in places	sh-lo	1-2 vf, 1 f	1-2 vf i	top: pat si	35-55 c>3 f>5	cs		bot: nc- f f co top: none
BCk	44	2.5Y 5/3	2.5Y 4/3		sg	lo	1-2 vf, 1 f	2-1 vf i, 1 f i	none	40-60 m>3 c>5	cs		bot: nc-pat f f co top: none
Ck	104+	10YR 6/3	10YR 4/3		sg	lo	1 f	1 f i	none	50-70 m>3 c-m>5	n/a		bot: v pat f f co top: none

Additional Notes:

Appendix 1 – Field Soil Descriptions for the Providence Mountains cont'd

Soil Profile Morphology

Location: Limestone Basin
Fountain Peak, CA, Quad

Landform: fan
Field ID: Pit#8
Lab ID: 06-2465 - 06-2469
Date Described: 05/18/06
Vegetation: creosote, yucca, barrel cacti
Slope Aspect: 2º WSW

Horz	Depth b.g.s. (cm)	Color Dry	Color Moist	Txt.	Structure	Consist.	Roots	pores	Cutans	Gravel %	Bdy	Diss	CaCO3
Av	4	10YR 6/3	10YR 4/3		1 m pr - 1-2 m pl	dso	1-2 vf	2 vf, v+I, 1 f v + i	bot: pat si	15-25 c>3 f>5	as		
Bwk1	11	10YR 6/3	2.5Y 4/3		2-1 m sbk	dsh-dso	2 vf, 1 f	1 vf t		15-25 c>3 f-c>5	cs		bot: pat f f co top: pat f f co
Bwk2	28	10YR 6/3	10YR 4/3		1-2 m+f sbk	dso	1-2 vf, 1 f	1 vf t		20-40 c>3 f>5	cs		bot: nc d f co top: pat f f po
BCk1	67	2.5Y 6/3	10YR 4/3		sg, 1 sbk in places	dlo-dso	1-2 vf, 1 f v f m	1-2 vf i+t	top: pat si co in places	40-60 m>3 c-m>5	cs		bot: nc d-p f co pat nc top: vt co
BCk2	85	10 YR 6/3	10 YR 4/2		sg	dlo	1-2 vf, 1 f	1-vf i		50-70 m>3 m>5	cs		bot: nc d -p f co pat nc
CK (CBk)	112+	10 YR 6/2	10 YR 5/2		sg	dlo	1 vf	2 vf i		50-70 m>3 m-c>5	n/a		bot: pat-nc f-d f co. top: pat v pat f f co

Additional Notes: No segragated CaCO3 in silt rich matrix; majority of clasts are angular with some sub-angular. Apparent increase in sub-angular clasts w/depth. No desert pavement on the surface, surface clasts have weak dissolution similar to Qf6 soils; debris lobes are not fresh, but still visible. No surface characteristics indicating a Qf5 surface.

Appendix 2 – General Field notes from the Providence Mountains

Basin	Field ID	Date	Landform	UTM Coordinates			Aspect	Depth (cms) b.g.s.	Colors	Notes
Granite Basin	HP#1	05/18/05	hillslope	11 S	630535	3871157	NE	4/39/39+	10YR 5/4; 10 YR 4/3	surface covered in highly fractured angular granite clasts/silty sand layer, mod. s.d. / silt as seen above w/m.g. sand and angular granitic clasts, mod. salt accumulation on fracture edges / highly fractured granite b.r. with substanial white cover, assumably salt, b.r. has a rotting appearance
	HP#2	05/18/05	hillslope	11 S	630539	3863665	NE	4/4+		surface similar to HP#1 / thin silt layer, mod. s.d. / rapidly grussifying b.r., extreme oxidation along fractures, white powder along fractures
	HP#3	5/18/2005 6/10/05	hillslope	11 S	630581	3863646	NE	4/17/17+	10YR 5/3	c.g. sand w/silt, minor ped formation, poorly indurated, / grussifying b.r., w/sand, no peds / highly weatherd b.r.
	HP#4	5/18/2005 6/10/05	hillslope	11 S	630683	3863544	NE	5/25/+	10 YR 5/3; 10 YR 5/4	silty sand, some peds, mod. Induration, / sand and silt with some b.r. fragments ranging in size, roots, evidence of insect activity / fractured weathered granite bedrock
	HP#5	05/18/05	hillslope	11 S	630685	3863531	NE	3/3+	10 YR 5/3	very thin silt layer, some loose peds / very fractured weathered granite, white powder along fractures
	HP#6	5/18/2005 6/10/05	hillslope	11 S	630766	3863460	NE	6/17+	10 YR 5/3; 10 YR 5/3	silty, sand, peds, roots, mod. development / silt w/some b.r. clasts, mod. development, some peds / fractured bedrock, white powder along fractures
	HP#7	05/18/05	hillslope	11 S	630757	3863464	NE	2/10+		sand and silt, loose peds, roots / silt layer with c.g. gravels and sand, roots, loose; it appears sed. filled in fractures in the b.r. and clasts
	HP#8	5/18/2005 6/10/05	hillslope	11 S	630776	3863494	NE	3/27+		silt and sand, peds mod. Indurated, roots / silt with sand and carbonate coated clasts, roots, insect burrows, peds / fractured weathered b.r.
	HP#10	05/18/05	hillslope	11 S	630800	3863539	SW	22/22+		silt with sand mod. s.d. / highly grussified, weatherd b.r.
	HP#11	05/18/05	hillslope	11 S	630845	3863544	SW	5/20+		highly weathered b.r., very susceptible to grussification/ highly grussified b.r., can be easily dug through, reddish hue
	HP#12	5/18/2005 6/10/05	hillslope	11 S	630848	3863575	SW	5/35+	10YR 5/4; 10 YR 5/5	silt w/sand, roots and peds / gravel and silt layer / same as above
	HP#13	5/18/2005 6/10/05	hillslope	11 S	630824	3863595	SW	0/5/42	10YR 5/4	silt, peds, roots, insect burrows/ c.g. sand w/silt, roots, peds, grussified b.r. clasts/ highly fractured b.r.
	HP#14	05/18/05	hillslope	n.m.	n.m.	n.m.	SW	17/17+		silty gravel hz., some s.d., impacted by bioturbation / highly weathered b.r.
	HP#15	05/18/05	hillslope	11 S	630618	3863678	SW			hit b.r. immediately, very thin amount of silt atop b.r.
	HP#16	05/18/05	hillslope	11 S	630617	3863689	SW			same as above
	HP#17	06/10/05	hillslope	n.m.	n.m.	n.m.	n.m.	3/8+	10 YR 5/2; 10 YR 5/4	silt w/gravels / sandy gravel w/peds and silt / bedrock
	CH#1	06/10/05	colluvial hollow	11 S	630593	3863848	W		10YR 5/4; 10 YR 5/4	silt w/sand, roots, peds / silt with sand and gravels, roots, peds / highly fractured b.r.
	CH#2	06/10/05	colluvial hollow	11 S	630615	3863840	SW	4/12+		silt w/some sand, roots, peds / silt w/sand and gravels, roots, minor peds / highly fractured
	CH#3	06/10/05	colluvial hollow	11 S	630616	3863819	SW	5/5+		roots, ped, silt w/some sand / highly fractured B.R.
	CH#4	06/10/05	colluvial apron	11 S	630641	3863807	SW	4/4+	10YR 5/4; 10 YR 5/4	very silty small amounts of minor peds, some gravels < 1" / fractured granite w/silt in interspaces, block, angular granitic clasts; very little sed.
	CH#5	06/10/05	colluvial hollow	11 S	630650	3863846	SW	4/31+		silt w/c.g. sand and roots, wk. peds / silt accumulation w/clasts >2 ", wk. peds / boulder size clasts
	CH#6	06/10/05	colluvial deposit	11 S	630663	3863853	SW	8/8+		silt w/c.g. sand and roots, wk. peds / silt accumulation w/clasts >2 ", wk. peds / boulder size clasts

Basin	Field ID	Date	Landform	UTM Coordinates			Aspect	Depth (cms) b.g.s.	Colors	Notes
Winston Basin	WB#1	06/11/05	fan-terrace	11 S	629359	3862940	0º N/W	19/81/108/134+	10 YR 5/3; 10 YR 5/4; 10 YR 5/3	very c.g. gravel sand w/some gravels, layering between sand and gravel is observed, no peds, no significant silt / fist size granitic clasts w/salt (?) along the clasts and c.g. sand, some layering between sand and gravels, roots, mod. Imbrication of angular clasts / c.g. sand banded appearance, slight cementation, come silt / c.g. sand w/minor silt, peds, most developed horizon, roots / angular clasts (fist size) dominated w/ c.g. sand, roots - active wash
	WB#3	06/11/05	fan-terrace	11 S	629340	3862913	0º N/W	10/58+	10 YR 5/3; 10 YR 5/3; 10 YR 5/4	c.g. sand, loose peds, roots, no silt / c.g. sand w/gravels, loose peds, sand, banding, roots / lg. angular granitic clasts w/c.g. sand
	WB#5	06/11/05	fan-terrace	11 S	629856	3862587	0º N/W	13/41+	10 YR 4/3; 10 YR 5/4; 10YR 5/4	surface covered in c.g. sand and small clasts, veg is large creosote and small desert shrubbery / c.g. sand w/some gravels, this layer is darker than previously seen hzs./ fist size clasts weathered w/smooth edges, c.g. sand in interspace areas / very c.g. layer, well sorted, somewhat indurated
	WB#6	06/11/05	fan-terrace	11 S	629600	3863022	0º N/W	13/63+	10 YR 5/3; 10 YR 5/3	same surface as WB#5 / c.g. sand with finer sand, some loose peds, roots / similar to above horizon with increasingly larger clasts w/depth.

Appendix 2 – General Field notes from the Providence Mountains cont'd

Basin	Field ID	Date	Landform	UTM Coordinates			Aspect	Depth (cms) b.g.s.	Colors	Notes
Limestone Basin	CS#4	06/12/05	fan-terrace	11 S	630428	3871306	N/W	28/28+		surface is hummocky and old debris flows are present; veg. is creosote, yuccas, and chollas / silt filing interspace areas between limestone clasrs, roots, no peds, clasts are imbricated / same as above, increasing carbonate deposition, stong carbonate on clast bottoms
	CS#8	06/12/05	fan-terrace	11 S	631439	3871592	N/W	10/56+		silt w/limestone clasts, some peds, roots / carbonate coated clasts w/silt in interspace areas, imbracation / same as above
	CS#11	06/12/05	hillslope	11 S	631770	3871485	NW	24/47+		very thick silt deposit in between rock "shelves", no strong soil development preserved / silt w/some carbonate coated clasts / same as above with more carbonate coating on clasts
	CS#12	06/12/05	fan-terrace	11 S	631903	3871262	0º N/W	14/14+		surface covered in small < 2" clasts, w/larger clasts that look colluvial in origin, surface clasts have dissolution / silt w/small clasts that have carbonate coated bottoms / clasts w/full carbonate coverage, silt in interspace areas
	CS#13	06/12/05	debris flow	11 S	632204	3871174	S	12/18+		clasts w/sand and silt, carbonate on clast bottoms / c.g. sand and clasts, > 2 cm w/carbonate on bottoms / same as above w/increasing clast size
	CS#17	06/12/05	colluvial deposit	11 S	632055	3871448	S	4/4+		surface covered in angular clasts, w/varying degrees of carbonate development / silt w/small gravels that have wk. carbonate coating / lg. clasts w/silt accumulation in interspace areas, clasts have strong carbonate coating
	CS#18	06/12/05	colluvial deposit	11 S	632068	3871412	S			same as above
	CS#18	06/12/05	colluvial deposit	11 S	632036	3871457	S			same as above
	CS#20	06/13/05	colluvial deposit	11 S	630647	n.m.	SW	4/4+		surface covered in limestoone clasts w/carbonate coating on the bottom / silt rich w/mod. developed peds / fractured bedrock w/strong carbonate coating
	CS#23	06/13/05	colluvial deposit	11 S	630943	3871606	SW	4/4+		silt layer w/some small (< 2") weakly carbonate coated clasts / gist size angular clasts, coated in carbonate, silt fills intersapce areas
	CS#25	06/13/05	colluvial deposit	11 S	630918	3871626	NE	6/6+		silt w/mod. ped devlopment / carbonate coated clasts w/silt in interspace areas
	CS# 27	06/13/05	hillslope	11 S	631193	3871381	NE	34/34+		very silty w/gravels < 2 cm / carbonate coated clasts and silt
	CS#30	06/13/05	colluvial deposit	11 S	631161	3871398	NE	4/4+		silt w/mod. peds some clasts / lg. clasts, highly weathered, mod. carbonate on clasts, silt in interspace areas
	CS#32	06/13/05	fan-terrace	11 S	630854	3871249	N/W	8/28/44+		silt w/limestone fragments / limestone clasts, graded, sorted bedding, silt in interspace areas / fist size clasts w/strong carbonate coating, silt and gravels in interspace areas
	Pit #4	05/01/06	fan-terrace	11 S	630857	3871239	SW	8/24+		very silty w/some sand and carbonate coated clasts, very loose / silty sand w/lg. fully coated clasts, loose peds / very loose silt and sand with increasing sub-angular clasts

Appendix 3 – Laboratory Results for Particle Size Distribution, Salts and pH in the Providence Mountains

	Lab ID #	Field ID	MOISTURE	GRAVEL	Particle Size Distribution of < 2 mm fraction				fractions of < 2 mm	Salts	pH	100% Total Sample		
					SAND	SILT		CLAY						
			g g^{-1}	>2 mm	>62.5 um	15 um	3 um	<3 um				Gravel	Sand	Fines
			- % -	- % -	- % -	- % -	- % -	- % -	- % -	- mg kg^{-1}		- % -	- % -	- % -
Granite Basin	05-1586	CH1 0-4	0.0037	41.10	68.8	12.9	11.0	7.2	100.0	286.35	6.32	41.10	40.53	18.37
	05-1587	CH1 4-9	0.0064	41.14	65.3	13.4	12.9	8.4	100.0	215.57	6.33	41.14	38.44	20.42
	05-1589	CH2 0-4	0.0032	33.40	60.7	17.0	13.7	8.6	100.0	330.84	6.39	33.40	40.43	26.13
	05-1590	CH2 4-12	0.0062	42.35	61.4	15.6	13.5	9.5	100.0	170.22	6.42	42.35	35.39	22.24
	05-1590DUP	CH2 4-12	0.0062	42.35	60.8	15.7	14.2	9.4	100.0	n.m.	n.m.	42.35	35.02	22.63
	05-1594	CH5 0-4	0.0035	34.16	66.0	13.8	12.0	8.2	100.0	769.66	6.30	34.16	43.48	22.33
	05-1595	CH5 4-31	0.0111	52.75	60.8	15.0	14.1	10.1	100.0	100.52	6.33	52.75	28.71	18.53
	05-1596	HP1 0-4	0.0079	29.78	73.8	9.4	9.5	7.3	100.0	140.48	6.37	29.78	51.80	18.40
	05-1597	HP1 4-39	0.0124	59.25	74.9	8.9	9.0	7.2	100.0	232.00	6.37	59.25	30.53	10.22
	05-1599	HP2 0-4	0.0077	38.87	80.6	7.8	6.9	4.8	100.0	75.69	6.37	38.87	49.26	11.87
	05-1601	HP3 0-4	0.0051	46.93	76.1	10.1	9.0	4.8	100.0	128.13	6.61	46.93	40.39	12.70
	05-1602	HP3 4-17	0.0197	55.90	67.4	8.9	13.6	10.1	100.0	80.48	6.23	55.90	29.70	14.39
	05-1604	HP4 0-5	0.0067	54.02	69.7	13.5	10.1	6.7	100.0	156.48	6.66	54.02	32.04	13.93
	05-1605	HP4 5-25	0.0144	46.26	60.3	15.9	13.9	9.8	100.0	173.04	6.33	46.26	32.43	21.33
	05-1607	HP5 0-3	0.0058	38.90	67.5	11.9	11.8	8.7	100.0	203.67	6.61	38.90	41.27	19.83
	05-1607DUP	HP5 0-3	0.0058	38.90	68.6	11.4	11.2	8.8	100.0	142.15	n.m.	38.90	41.90	19.19
	05-1609	HP6 0-6	0.0080	49.02	70.6	13.3	9.7	6.4	100.0	99.52	6.65	49.02	36.00	14.98
	05-1610	HP6 6-17	0.0124	50.32	63.4	14.7	12.5	9.5	100.0	273.69	6.35	50.32	31.51	18.19
	05-1612	HP7 0-2	0.0057	55.97	67.8	13.5	11.0	7.7	100.0	183.95	6.51	55.97	29.86	14.17
	05-1613	HP7 2-10	0.0145	63.98	60.6	12.1	15.5	11.9	100.0	248.32	6.46	63.98	21.82	14.20
	05-1615	HP8 0-3	0.0076	32.89	76.0	9.5	8.9	5.7	100.0	186.77	6.59	32.89	51.01	16.10
	05-1616	HP8 3-27	0.0064	64.60	74.1	10.2	9.2	6.5	100.0	234.75	6.47	64.60	26.23	9.18
	05-1618	HP11 0-5	0.0067	23.10	69.8	12.5	10.2	7.5	100.0	126.72	6.65	23.10	53.71	23.19
	05-1619	HP11 BR	0.0157	83.73	67.3	10.9	11.8	10.1	100.0	483.19	6.52	83.73	10.94	5.33
	05-1620	HP12 0-5	0.0042	94.23	71.2	9.7	11.9	7.2	100.0	250.56	6.58	94.23	4.11	1.66
	05-1621	HP12 5-34	0.0079	40.94	65.3	11.3	14.0	9.4	100.0	149.48	6.52	40.94	38.56	20.53
	05-1622	HP12 BR	0.0037	85.55	64.5	11.6	14.2	9.7	100.0	242.24	n.m.	85.55	9.32	5.13
	05-1623	HP13 0-5	0.0043	38.91	69.1	12.4	11.3	7.2	100.0	152.97	6.35	38.91	42.24	18.87
	05-1624	HP13 5-35	0.0069	49.15	68.1	11.7	12.1	8.1	100.0	157.12	6.35	49.15	34.65	16.20
	05-1626	HP17 0-3	0.0069	34.40	70.2	10.7	11.1	8.0	100.0	158.08	6.37	34.40	46.03	19.55
	05-1627	HP17 3-8	0.0084	44.46	69.2	10.3	12.1	8.4	100.0	106.24	6.39	44.46	38.41	17.12

Lab ID # - from DRI Soils Lab
Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface
g g-1 - indicating grams/grams

Appendix 3 – Laboratory Results for Particle Size Distribution, Salts and pH in the Providence Mountains cont'd

	Lab ID #	Field ID	MOISTURE	GRAVEL	Particle Size Distribution of < 2 mm fraction				fractions of < 2 mm	Salts	pH	100% Total Sample		
					SAND	SILT		CLAY						
			$g\ g^{-1}$	>2 mm	>62.5 um	15 um	3 um	<3 um				Gravel	Sand	Fines
			- % -	- % -	- % -	- % -	- % -	- % -	- % -	- $mg\ kg^{-1}$		- % -	- % -	- % -
Granite Basin	06-831	GB4 UNIT 1	0.0049	36.25	72.3	12.9	9.0	5.8	100.0	249.27	6.52	36.25	46.09	17.66
	06-832	GB4 UNIT 2	0.0088	33.11	75.6	10.7	8.0	5.7	100.0	163.88	6.48	33.11	50.59	16.30
	06-833	GB4 UNIT 3	0.0085	33.76	53.6	21.8	14.5	10.1	100.0	166.81	6.46	33.76	35.49	30.74
	06-834	GB4 UNIT 4	0.0089	30.75	66.7	15.1	10.3	7.9	100.0	92.51	6.46	30.75	46.19	23.04
	06-835	GB4 UNIT 5	0.0137	40.35	66.8	15.2	10.3	7.7	100.0	121.90	6.48	40.35	39.84	19.81
	06-836	GB4 UNIT 6	0.0245	37.43	66.6	14.2	10.7	8.4	100.0	81.28	6.46	37.43	41.70	20.87
	06-837	GB8 UNIT 1	0.0058	47.14	77.4	10.7	7.4	4.4	100.0	184.86	6.28	47.14	40.91	11.95
	06-838	GB8 UNIT 2	0.0125	47.46	74.6	11.5	8.2	5.6	100.0	160.00	6.32	47.46	39.20	13.33
	06-839	GB8 UNIT 3	0.0168	41.42	70.3	12.8	9.1	7.8	100.0	129.66	6.35	41.42	41.17	17.39
	06-840	GB8 UNIT 4	0.0137	40.45	65.9	14.5	10.8	8.8	100.0	134.11	6.37	40.45	39.23	20.32
	06-841	GB8 UNIT 5	0.0105	54.76	68.3	12.9	10.3	8.5	100.0	143.37	6.37	54.76	30.89	14.35
	06-842	GB20 UNIT 1	0.0031	22.20	71.4	18.6	6.9	3.0	100.0	190.51	6.23	22.20	55.59	22.22
	06-843	GB20 UNIT 2	0.0078	15.45	64.7	20.6	10.0	4.7	100.0	162.90	6.24	15.45	54.73	29.85
	06-844	GB20 UNIT 3	0.0078	30.68	70.4	15.0	8.5	6.1	100.0	161.93	6.21	30.68	48.80	20.52
	06-845	GB20 UNIT 4	0.0085	39.71	73.1	13.3	8.0	5.6	100.0	109.88	6.17	39.71	44.07	16.20
	06-846	GB20 UNIT 5	0.0146	32.87	76.4	11.2	7.2	5.2	100.0	88.82	6.26	32.87	51.28	15.83
	06-1736	GB3 unit 1 @ 3.8	0.0394	42.06	73.2	13.0	8.4	5.4	100.0	187.32	6.04	42.06	42.41	15.52
	06-1737	GB3 unit 2 @ 11.5	n.m.	n.m.	86.1	5.8	4.6	3.4	100.0	176.59	6.06	n.m.	n.m	n.m.
	06-1738	GB3 unit 3 @ 22.5	0.0075	49.78	73.6	11.0	8.9	6.6	100.0	114.93	6.08	49.78	36.94	13.29
	06-1739	GB3 unit 4 @ 31.6	0.0081	47.87	71.2	13.1	8.9	6.8	100.0	136.00	6.06	47.87	37.13	15.01
	06-1740	GB3 unit 5 @ 41	0.0120	38.42	70.4	11.4	10.0	8.2	100.0	163.39	6.10	38.42	43.37	18.21

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g g-1 - indicating grams/grams

Appendix 3 – Laboratory Results for Particle Size Distribution, Salts and pH in the Providence Mountains cont'd

	Lab ID #	Field ID	MOISTURE	GRAVEL	Particle Size Distribution of < 2 mm fraction				fractions of < 2 mm	Salts	pH	100% Total Sample		
					SAND	SILT		CLAY						
			$g\ g^{-1}$	>2 mm	>62.5 um	15 um	3 um	<3 um				Gravel	Sand	Fines
			- % -	- % -	- % -	- % -	- % -	- % -	- % -	- $mg\ kg^{-1}$		- % -	- % -	- % -
Winston Basin	05-1629	WB1 0-19	0.0036	48.58	96.4	1.0	1.5	1.0	100.0	234.09	6.46	48.58	49.59	1.83
	05-1630	WB1 81-108	0.0138	68.34	81.1	8.0	6.8	4.1	100.0	95.94	6.44	68.34	25.67	5.99
	05-1630DUP	WB1 81-108	0.0138	68.34	80.6	8.4	6.8	4.2	100.0	n.m.	n.m.	68.34	25.50	6.15
	05-1631	WB2 0-12	0.0051	30.27	83.3	8.1	5.2	3.4	100.0	127.81	6.42	30.27	58.09	11.64
	05-1632	WB2 12-?	0.0103	30.26	85.1	6.5	5.3	3.1	100.0	100.60	6.46	30.26	59.35	10.39
	05-1633	WB3 0-10	0.0036	51.09	83.7	8.8	4.7	2.8	100.0	101.88	n.m.	51.09	40.93	7.99
	05-1634	WB3 10-58	0.0060	47.99	82.1	8.9	5.3	3.7	100.0	159.68	6.46	47.99	42.71	9.30
	05-1635	WB3 58-?	0.0054	74.31	90.8	3.7	3.3	2.2	100.0	118.88	6.49	74.31	23.34	2.35
	05-1636	WB4 0-4	0.0088	26.31	76.9	9.1	7.8	6.3	100.0	67.25	6.51	26.31	56.63	17.08
	06-480	WB5 0-13 cm	0.0042	39.43	86.4	5.7	4.7	3.2	100.0	270.40	6.31	39.43	52.34	8.22
	06-481	WB5 13-41cm	0.0032	70.40	90.4	3.4	3.6	2.6	100.0	116.91	6.40	70.40	26.77	2.83
	06-482	WB5 41-? cm	0.0030	67.33	91.6	2.9	3.0	2.5	100.0	104.63	6.43	67.33	29.91	2.75
	05-1638	WB6 0-13	0.0038	31.23	83.5	8.8	4.8	2.9	100.0	n.m.	6.37	31.23	57.42	11.35
	05-1639	WB6 13-52	0.0074	32.07	85.0	7.2	4.4	3.5	100.0	n.m.	6.42	32.07	57.73	10.19
	05-1640	WB6 52-?	0.0119	33.35	88.1	4.9	4.2	2.8	100.0	50.56	6.40	33.35	58.73	7.92
	06-1741	WB7 unit 1 @ 0.8	0.0056	33.32	79.6	10.9	6.3	3.2	100.0	243.96	6.02	33.32	53.10	13.58
	06-1742	WB7 unit 2 @ 3.5	0.0069	29.30	72.7	13.4	8.5	5.4	100.0	122.16	6.10	29.30	51.42	19.26
	06-1743	WB7 unit 3 @ 8.7	0.0047	38.70	83.9	7.2	5.2	3.6	100.0	252.85	6.15	38.70	51.43	9.86
	06-1744	WB7 unit 4 @ 26.0	0.0039	41.85	86.7	5.9	4.3	3.1	100.0	140.44	6.24	41.85	50.41	7.74
	06-1745	WB7 unit 5 @ 32.0	0.0033	74.82	80.6	8.7	6.8	4.0	100.0	292.54	6.28	74.82	20.29	4.89
	06-1746	WB8 unit 1 @ 0.7	0.0029	22.88	83.2	9.6	4.8	2.4	100.0	218.38	6.15	22.88	64.20	12.94
	06-1747	WB8 unit 2 @ 3	0.0034	25.62	75.0	13.0	7.6	4.4	100.0	90.10	6.06	25.62	55.81	18.55
	06-1748	WB8 unit 3 @ 11.7	0.0072	32.09	75.7	11.6	7.4	5.3	100.0	172.74	6.13	32.09	51.40	16.51
	06-1749	WB8 unit 4 @ 20.0	0.0067	40.74	74.2	12.8	7.7	5.2	100.0	104.25	6.15	40.74	43.98	15.28
	06-1750	WB8 unit 5 @ 30	0.0063	43.85	79.7	9.4	6.4	4.5	100.0	100.80	6.21	43.85	44.75	11.40
	06-1751	WB8 unit 6 @ 40	0.0077	46.89	84.1	6.8	5.4	3.7	100.0	226.43	6.23	46.89	44.67	8.42
	05-1641	WB7	0.0026	54.53	95.8	1.3	1.8	1.1	100.0	272.29	6.46	54.53	43.55	1.92
	05-1641DUP	WB7	0.0026	54.53	95.1	1.6	2.0	1.3	100.0	n.m.	n.m.	54.53	43.24	2.24
	05-1642	WB8	0.0028	18.54	95.3	1.4	2.0	1.3	100.0	181.95	6.33	18.54	77.63	3.83
	05-1643	WB9	0.0023	39.44	97.9	0.3	1.0	0.7	100.0	118.48	6.39	39.44	59.31	1.24
	05-1644	WB10	0.0025	55.03	94.8	1.6	2.3	1.3	100.0	181.95	6.51	55.03	42.64	2.34

Lab ID # - from DRI Soils Lab
Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface
g g-1 - indicating grams/grams

Appendix 3 – Laboratory Results for Particle Size Distribution, Salts and pH in the Providence Mountains cont'd

	Lab ID #	Field ID	MOISTURE	GRAVEL	Particle Size Distribution of < 2 mm fraction				☐fractions of < 2 mm	Salts	pH	100% Total Sample		
					SAND	SILT		CLAY						
			g g^{-1}	>2 mm	>62.5 um	15 um	3 um	<3 um				Gravel	Sand	Fines
			- % -	- % -	- % -	- % -	- % -	- % -	- % -	- mg kg^{-1}		- % -	- % -	- % -
Limestone Basin	05-1645	CS11 0-14	0.0077	37.41	41.0	30.8	16.2	12.0	100.0	231.39	6.44	37.41	25.67	36.92
	05-1647	CS17 0-4	0.0058	31.36	45.0	32.3	14.3	8.4	100.0	215.76	6.42	31.36	30.90	37.74
	05-1647DUP	CS17 0-4	0.0058	31.36	44.1	32.6	14.5	8.8	100.0	n.m.	n.m.	31.36	30.30	38.35
	05-1648	CS17 4-12	0.0042	53.85	45.4	32.2	14.0	8.3	100.0	247.19	6.49	53.85	20.96	25.18
	05-1649	CS18 0-4	0.0042	38.17	41.9	29.7	16.3	12.1	100.0	205.94	6.58	38.17	25.88	35.94
	05-1650	CS18 4-?	0.0049	45.67	44.5	26.3	15.8	13.4	100.0	283.91	6.65	45.67	24.18	30.15
	05-1651	CS20 0-4	0.0080	34.16	36.3	26.2	16.6	20.8	99.9	n.m.	6.72	34.16	23.92	41.87
	05-1654	CS22 37-66	0.0012	39.63	53.8	25.1	12.8	8.3	100.0	152.37	6.46	39.63	32.45	27.91
	05-1655	CS22 66-?	0.0042	54.05	49.8	26.5	13.5	10.3	100.2	209.52	6.49	54.05	22.90	23.13
	05-1656	CS 23 0-4	0.0031	49.72	46.2	25.8	16.0	11.9	100.0	547.07	6.56	49.72	23.24	27.04
	05-1657	CS23 4-?	0.0082	42.48	37.9	28.6	19.1	14.3	100.0	272.38	6.66	42.48	21.83	35.69
	05-1658	CS25 0-6	0.0050	43.37	51.4	27.7	13.5	7.4	100.0	443.20	6.70	43.37	29.10	27.53
	05-1659	CS25 6-?	0.0077	32.16	44.3	31.2	14.3	10.3	100.1	287.74	6.80	32.16	30.06	37.85
	05-1660	CS26 0-30	0.0017	69.06	60.7	20.1	10.8	8.4	100.0	212.91	6.87	69.06	18.78	12.16
	05-1661	CS28 0-30	0.0136	27.36	39.8	32.0	16.9	11.3	100.1	215.24	6.40	27.36	28.94	43.77
	05-1661DUP	CS28 0-30	0.0136	27.36	42.2	30.6	15.8	11.4	100.0	n.m.	n.m.	27.36	30.62	42.02
	05-1662	CS29 0-30	0.0105	27.31	40.4	31.2	16.7	11.7	99.9	305.98	6.44	27.31	29.35	43.27
	05-1663	CS29 30-62	0.0205	41.21	29.2	21.0	19.4	30.5	100.1	264.86	6.47	41.21	17.19	41.66
	05-1664	CS30 0-4	0.0054	34.08	41.1	33.2	15.4	10.4	100.1	230.16	6.51	34.08	27.10	38.87
	05-1665	CS30 4-?	0.0113	21.64	38.8	33.7	16.1	11.4	100.0	260.00	6.54	21.64	30.43	47.94
	05-1666	CS31 0-10	0.0029	49.60	48.8	28.4	14.1	8.7	99.9	256.00	6.37	49.60	24.59	25.76
	05-1667	CS32 0-8	0.0058	57.03	57.2	19.8	12.9	10.2	100.1	260.83	6.42	57.03	24.57	18.43
	05-1668	CS32 8-28	0.0012	72.84	57.9	21.4	10.6	10.1	99.9	189.21	6.47	72.84	15.72	11.43
	05-1669	CS32 28-48	0.0006	81.48	61.7	20.0	9.7	8.6	100.0	200.96	6.51	81.48	11.42	7.10
	06-474	CF 0-4 cm	0.0029	26.32	73.8	15.3	7.2	3.7	100.0	301.87	6.04	26.32	54.40	19.27
	06-475	CF 4-24 cm	0.0050	35.13	75.2	12.1	7.5	5.2	100.0	167.92	6.16	35.13	48.79	16.10
	06-476	CF 24- 44 cm	0.0054	65.48	75.4	11.4	7.6	5.7	100.0	131.31	6.14	65.48	26.02	8.51
	06-485	CS4 0-28 cm	0.0015	71.15	61.0	22.9	9.3	6.7	100.0	219.48	6.55	71.15	17.60	11.24
	06-486	CS4 28-?	0.0011	59.17	64.5	18.9	8.9	7.8	100.0	216.49	6.67	59.17	26.34	14.50
	06-488	CS8 0-10 cm	0.0043	42.64	40.5	31.0	17.4	11.2	100.0	360.79	6.78	42.64	23.22	34.14
	06-489	CS8 10 -56 cm	0.0026	51.90	46.1	24.5	16.0	13.4	100.0	253.15	6.85	51.90	22.18	25.92
	06-490	CS8 10-56 cm	0.0028	33.92	48.0	24.7	13.8	13.5	100.0	229.66	6.95	33.92	31.72	34.36
	06-491	CS11 0-24 cm	0.0070	41.84	40.5	35.2	16.1	8.2	100.0	359.68	6.97	41.84	23.58	34.58
	06-492	CS11 24-57 cm	0.0105	48.60	37.1	33.5	18.7	10.5	99.9	327.30	7.02	48.60	19.09	32.26
	06-493	CS16 0-16	0.0032	35.78	43.4	28.2	16.4	12.1	100.0	294.79	7.00	35.78	27.84	36.38
	06-495	CS13 0-12 cm	0.0008	58.13	58.7	22.1	11.3	8.0	100.1	226.80	7.07	58.13	24.56	17.35
	06-496	CS13 12-18 cm	0.0010	57.02	59.7	21.2	10.8	8.3	100.0	191.23	7.10	57.02	25.64	17.34

Lab ID # - from DRI Soils Lab
Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface
g g-1 - indicating grams/grams

Appendix 3 – Laboratory Results for Particle Size Distribution, Salts and pH in the Providence Mountains cont'd

	Lab ID #	Field ID	MOISTURE	GRAVEL	Particle Size Distribution of < 2 mm fraction				fractions of < 2 mm	Salts	pH	100% Total Sample		
					SAND	SILT		CLAY						
			g g^{-1}	>2 mm	>62.5 um	15 um	3 um	<3 um				Gravel	Sand	Fines
			- % -	- % -	- % -	- % -	- % -	- % -	- % -	- mg kg^{-1}		- % -	- % -	- % -
Limestone Basin	06-2444	LB1A - Avj - 1	0.0025	40.11	59.1	22.3	10.8	7.9	100.0	247.58	7.70	40.11	35.37	24.52
	06-2444 DUP	LB1A - Avj - 1	0.0025	40.11	62.2	20.2	10.1	7.5	100.0	236.51	7.62	40.11	37.25	22.64
	06-2445	LB1A - Bwk -2	0.0047	28.34	48.7	28.1	14.0	9.3	100.1	290.09	7.55	28.34	34.92	36.80
	06-2446	LB1A - BCk1 -3	0.0091	34.71	47.9	24.8	15.7	11.5	100.0	277.92	n.d.	34.71	31.30	33.99
	06-2447	LB1A - BCk2 -4	0.0119	46.54	42.7	20.4	19.0	17.9	100.0	312.64	7.46	46.54	22.82	30.64
	06-2448	LB1B - Av - 1	0.0015	27.21	54.8	26.6	11.7	6.9	100.0	260.85	7.48	27.21	39.89	32.90
	06-2449	LB1B - Bwk -2	0.0036	36.39	57.6	23.8	11.1	7.5	100.0	275.03	7.50	36.39	36.67	26.95
	06-2450	LB1B - BCk1 -3	0.0039	65.55	58.6	22.8	10.9	7.7	99.9	287.60	7.50	65.55	20.19	14.24
	06-2451	LB1B - BCk2 - 4	0.0031	55.31	56.1	24.5	11.5	7.9	100.0	254.94	7.72	55.31	25.08	19.61
	06-2452	LB5 - Av -1	0.0048	38.55	57.1	27.3	10.2	5.5	100.1	255.56	7.63	38.55	35.08	26.41
	06-2453	LB5 - Bwk -2	0.0062	38.15	52.3	25.2	12.8	9.7	100.1	235.73	7.62	38.15	32.35	29.55
	06-2454	LB5 - Bk -3	0.0035	48.56	61.0	21.5	10.1	7.3	100.0	255.77	7.58	48.56	31.39	20.05
	06-2454 DUP	LB5 - Bk -3	0.0035	48.56	61.1	21.5	10.0	7.3	99.9	238.33	7.51	48.56	31.43	19.99
	06-2455	LB6 - Avj - 1	0.3504	71.45	66.9	20.3	8.5	4.2	99.9	405.35	7.44	71.45	19.10	9.43
	06-2456	LB6 - CAk - 2	0.0033	47.51	74.6	15.2	6.4	3.7	100.0	328.19	7.48	47.51	39.15	13.34
	06-2457	LB6 - Ck1 -3	0.0011	63.96	72.9	15.3	6.9	4.8	100.0	232.91	7.46	63.96	26.29	9.73
	06-2458	LB6 - Ck2 - 4	0.0021	59.21	72.7	14.4	7.7	5.1	100.0	264.22	7.44	59.21	29.67	11.12
	06-2459	LB6 - Ck3 - 5	0.0033	51.82	78.6	10.8	6.0	4.6	100.0	263.27	7.44	51.82	37.86	10.34
	06-2460	LB7 - 1	0.0067	47.15	53.7	22.8	12.9	10.5	100.0	278.64	7.46	47.15	28.38	24.47
	06-2461	LB7 - 2	0.0043	61.93	45.8	25.8	16.7	11.7	100.0	339.32	7.50	61.93	17.45	20.62
	06-2462	LB7 - 3	0.0047	61.32	48.2	24.1	16.3	11.4	100.0	273.83	7.51	61.32	18.63	20.05
	06-2463	LB7 - 4	0.0084	44.03	49.9	23.0	15.9	11.3	100.1	293.47	7.55	44.03	27.95	28.06
	06-2464	LB8 - Av -1	0.0028	49.75	56.8	26.2	10.4	6.6	100.0	254.89	7.44	49.75	28.54	21.71
	06-2464 DUP	LB8 - Av -1	0.0028	49.75	60.1	24.1	9.7	6.1	100.0	247.38	7.41	49.75	30.20	20.05
	06-2465	LB8 - Bwk1 - 2	0.0072	29.07	49.2	27.4	13.5	9.7	99.9	221.98	7.39	29.07	34.93	35.95
	06-2466	LB8 - Bwk2 - 3	0.0105	40.37	46.0	29.9	14.5	9.6	100.0	220.74	7.44	40.37	27.45	32.18
	06-2467	LB8 - BCk1 - 4	0.0185	38.72	52.0	25.1	13.6	9.3	100.0	254.02	7.46	38.72	31.85	29.43
	06-2468	LB8 - BCk2 - 5	0.0054	74.54	55.2	23.0	12.7	9.0	100.0	229.48	7.50	74.54	14.06	11.40
	06-2469	LB8 - Ck - 6	0.0031	74.16	72.4	14.7	7.6	5.4	100.0	196.07	7.48	74.16	18.70	7.15
	06-2470	LB9 - Av -1	0.0140	29.54	56.0	19.6	12.4	12.0	100.0	229.31	7.44	29.54	39.42	31.04
	06-2471	LB9 - Bwk - 2	0.0068	26.32	62.4	18.1	10.4	9.2	100.0	245.40	7.48	26.32	45.98	27.71
	06-2472	LB9 - Bk - 3	0.0059	40.23	61.8	19.8	10.3	8.1	100.1	229.84	7.50	40.23	36.96	22.84
	06-2473	LB9 - BCk - 4	0.0067	57.90	67.5	17.6	8.4	6.5	100.1	248.08	7.53	57.90	28.44	13.69
	06-2474	LB9 - CBk - 5	0.0091	55.71	78.7	10.8	5.7	4.8	100.0	202.22	7.50	55.71	34.84	9.43
	06-2474 DUP	LB9 - CBk - 5	0.0091	55.71	75.9	12.2	6.5	5.5	100.0	212.82	7.51	55.71	33.60	10.69
	06-2475	LB9 - Ck1 - 6	0.0023	77.39	87.9	6.0	3.4	2.7	100.0	217.87	7.55	77.39	19.87	2.73
	06-2476	LB9 - Ck2 - 7	0.0040	56.92	77.0	12.6	6.0	4.4	100.0	207.19	7.58	56.92	33.17	9.91

Lab ID # - from DRI Soils Lab
Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface
g g-1 - indicating grams/grams

Appendix 4 – Results of XRF analysis in the Providence Mountains

Granite Basin Samples								
XRF Lab ID	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 06**	**GIF 06**
LAB ID	**05-1596a**	**05-1596B**	**05-1598**	**05-1594a**	**05-1594B**	**05-1595**	**06-474a**	**06-474B**
Sample	**silt**	**sand**	**bedrock**	**silt**	**sand**	**bedrock**	**silt**	**sand**
Unnormalized Major Elements (Weight %):								
SiO2	62.19	61.72	65.44	63.85	66.07	64.02	64.53	66.67
TiO2	1.049	1.106	0.843	1.069	0.684	0.764	1.072	0.795
Al2O3	16.78	15.65	14.46	16.32	16.50	16.48	15.85	15.43
FeO*	6.46	8.87	8.44	5.68	4.43	3.90	5.58	4.10
MnO	0.115	0.142	0.083	0.108	0.080	0.062	0.105	0.069
MgO	2.41	2.19	1.10	2.38	1.90	3.02	2.62	1.81
CaO	3.85	2.95	3.07	3.42	1.99	3.30	3.51	2.29
Na2O	2.98	2.88	3.00	2.79	3.26	3.74	3.01	3.55
K2O	2.55	2.61	2.27	2.95	4.14	4.10	3.07	4.18
P2O5	0.395	0.340	0.497	0.243	0.178	0.216	0.325	0.224
Sum	98.78	98.45	99.21	98.83	99.23	99.59	99.67	99.10
LOI (%)	**5.50**	**3.63**	**2.01**	**6.03**	**4.07**	**2.04**	**4.64**	**2.62**
Normalized Major Elements (Weight %):								
SiO2	62.96	62.70	65.96	64.61	66.59	64.28	64.75	67.27
TiO2	1.062	1.124	0.850	1.082	0.689	0.767	1.075	0.802
Al2O3	16.98	15.90	14.58	16.52	16.63	16.55	15.90	15.57
FeO*	6.54	9.01	8.51	5.75	4.47	3.91	5.60	4.14
MnO	0.117	0.144	0.084	0.109	0.080	0.062	0.105	0.069
MgO	2.44	2.23	1.11	2.41	1.91	3.03	2.63	1.82
CaO	3.90	2.99	3.09	3.46	2.00	3.31	3.52	2.31
Na2O	3.02	2.92	3.03	2.83	3.28	3.75	3.02	3.58
K2O	2.58	2.65	2.29	2.99	4.17	4.12	3.08	4.22
P2O5	0.400	0.35	0.501	0.245	0.179	0.217	0.326	0.226
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Appendix 4 – Results of XRF analysis in the Providence Mountains cont'd

Granite Basin Samples								
XRF Lab ID	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 06**	**GIF 06**
LAB ID	**05-1596a**	**05-1596B**	**05-1598**	**05-1594a**	**05-1594B**	**05-1595**	**06-474a**	**06-474B**
Sample	**silt**	**sand**	**bedrock**	**silt**	**sand**	**bedrock**	**silt**	**sand**
Unnormalized Trace Elements (ppm):								
Ni	34	35	33	40	31	41	36	25
Cr	65	59	28	60	53	114	53	23
Sc	18	18	15	16	12	16	17	10
V	110	134	83	113	85	114	109	91
Ba	768	815	375	769	1038	636	815	1079
Rb	99	87	67	114	130	111	117	138
Sr	390	329	280	369	332	428	392	359
Zr	1042	398	563	818	305	306	658	271
Y	54	43	59	53	34	36	47	29
Nb	21.1	13.7	7.3	23.2	14.7	18.3	22.2	16.8
Ga	24	24	26	20	20	19	23	18
Cu	33	35	74	27	18	21	25	16
Zn	85	113	72	83	53	41	91	52
Pb	22	19	17	20	15	19	25	16
La	72	59	76	83	64	48	64	56
Ce	144	116	145	151	116	108	124	103
Th	20	9	9	22	11	11	20	11
Nd	64	53	72	72	49	40	57	43
U	5	1	2	4	4	2	4	3
	U is semi-quantitative at this level							
sum tr.	3000	2306	1927	2780	2331	2088	2636	2315
in %	0.30	0.23	0.19	0.28	0.23	0.21	0.26	0.23
sum m+tr	99.08	98.68	99.40	99.10	99.46	99.80	99.94	99.34
Total m+tr as oxides	99.16	98.74	99.46	99.18	99.51	99.85	100.00	99.39

Unnormalized Trace Elements (ppm):								
NiO	42.8	44.9	41.6	50.4	39.8	52.3	45.6	31.4
Cr2O3	95.0	86.7	40.5	87.8	77.0	166.3	77.5	33.3
Sc2O3	27.9	27.8	22.4	24.2	18.9	25.2	25.3	15.2
V2O3	162.4	196.7	121.4	165.6	125.6	168.1	160.2	133.3
BaO	857.1	910.4	418.8	858.7	1158.7	709.8	909.4	1205.0
Rb2O	107.8	94.7	73.2	125.1	141.8	121.2	127.7	150.9
SrO	461.0	389.2	331.1	436.1	392.9	506.4	463.7	424.6
ZrO2	1422.4	543.4	768.3	1116.1	415.8	418.3	897.6	370.4
Y2O3	67.9	54.7	74.3	67.3	43.4	45.8	59.9	37.3
Nb2O5	30.2	19.6	10.4	33.2	21.0	26.2	31.8	24.0
Ga2O3	32.4	31.6	34.4	27.4	27.3	25.1	31.2	24.2
CuO	41.8	44.3	92.5	34.0	22.8	26.0	30.9	20.3
ZnO	106.7	141.3	90.7	103.7	66.0	51.2	114.1	65.6
PbO	23.3	19.9	18.4	21.3	16.4	20.6	26.4	16.7
La2O3	84.3	69.4	89.2	97.0	74.7	56.8	75.1	65.7
CeO2	177.3	142.6	178.6	185.5	142.0	132.3	152.6	127.1
ThO2	22.3	9.6	9.5	24.7	11.9	12.6	21.6	12.5
Nd2O3	74.2	61.2	83.7	83.9	56.7	46.4	66.0	49.9
sum tr.	**3837**	**2888**	**2499**	**3542**	**2853**	**2611**	**3317**	**2807**
in %	**0.38**	**0.29**	**0.25**	**0.35**	**0.29**	**0.26**	**0.33**	**0.28**

Appendix 4 – Results of XRF analysis in the Providence Mountains cont'd

Limestone Basin Samples											
GIF 05	**GIF 05**	**GIF 05**	**GIF 06**	**GIF 06**	**GIF 05**	**GIF 05**	**GIF05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**
05-1661a	**05-1661b**	**05-1661c**	**06-491a**	**06-491b**	**05-1647a**	**05-1647b**	**05-1648**	**05-1596B**	**05-1596bR**	**05-1661c**	**05-1661cR***
silt	**sand**	**bedrock**	**silt**	**sand**	**silt**	**sand**	**bedrock**	**sand**	**bedrock**		
Unnormalized Major Elements (Weight %):											
60.94	58.84	23.07	60.06	60.81	59.97	46.65	2.64	61.72	62.05	23.07	22.83
1.082	0.560	0.106	1.050	0.614	0.967	0.390	0.03	1.106	1.117	0.106	0.107
15.14	13.68	2.14	14.82	14.56	14.78	10.39	0.38	15.65	15.76	2.14	2.10
5.37	3.21	0.71	5.20	3.61	4.97	2.32	0.25	8.87	9.09	0.71	0.73
0.113	0.092	0.059	0.123	0.099	0.113	0.087	0.07	0.142	0.143	0.059	0.059
3.84	4.68	22.87	4.38	4.76	2.99	2.67	0.96	2.19	2.19	22.87	22.66
6.80	10.25	43.62	7.49	8.52	8.99	30.12	89.69	2.95	2.99	43.62	43.38
2.48	2.79	0.12	2.60	2.97	2.65	2.22	0.05	2.88	2.89	0.12	0.13
2.78	2.90	0.67	2.72	3.03	2.65	2.16	0.05	2.61	2.62	0.67	0.66
0.220	0.111	0.059	0.285	0.161	0.312	0.141	0.07	0.340	0.344	0.059	0.059
98.76		93.43	98.72	99.13	98.40	97.15	94.19	98.45	99.19	93.43	92.71
8.81	**11.24**	**38.53**	**10.15**	**11.64**	**9.14**	**20.77**	**42.41**	low d.t. Li, Be or B? Prob not S, since bead loi same			
Normalized Major Elements (Weight %):											
61.71	60.58	24.69	60.84	61.35	60.95	48.02	2.80	62.70	62.56	24.69	24.62
1.096	0.576	0.114	1.064	0.619	0.982	0.402	0.037	1.124	1.127	0.114	0.115
15.33	14.09	2.29	15.01	14.69	15.02	10.70	0.40	15.90	15.89	2.29	2.26
5.43	3.30	0.76	5.27	3.64	5.05	2.39	0.26	9.01	9.16	0.76	0.79
0.115	0.094	0.063	0.125	0.100	0.115	0.089	0.070	0.144	0.144	0.063	0.064
3.89	4.82	24.48	4.43	4.80	3.04	2.74	1.02	2.23	2.21	24.48	24.44
6.88	10.56	46.69	7.59	8.60	9.13	31.00	95.22	2.99	3.02	46.69	46.79
2.52	2.88	0.13	2.64	2.99	2.70	2.29	0.05	2.92	2.91	0.13	0.14
2.82	2.98	0.72	2.75	3.06	2.70	2.22	0.06	2.65	2.64	0.72	0.71
0.223	0.114	0.063	0.289	0.162	0.317	0.145	0.075	0.35	0.347	0.063	0.064
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Appendix 4 – Results of XRF analysis in the Providence Mountains cont'd

Limestone Basin Samples											
GIF 05	**GIF 05**	**GIF 05**	**GIF 06**	**GIF 06**	**GIF 05**	**GIF 05**	**GIF05**	**GIF 05**	**GIF 05**	**GIF 05**	**GIF 05**
05-1661a	**05-1661b**	**05-1661c**	**06-491a**	**06-491b**	**05-1647a**	**05-1647b**	**05-1648**	**05-1596B**	**05-1596bR**	**05-1661c**	**05-1661cR***
silt	**sand**	**bedrock**	**silt**	**sand**	**silt**	**sand**	**bedrock**	**sand**	**bedrock**		
Unnormalized Trace Elements (ppm):											
36	24	10	31	26	41	21	19	35	33	10	10
62	29	11	58	35	57	24	11	59	58	11	12
15	10	6	15	10	15	10	6	18	19	6	5
108	62	18	105	66	100	48	15	134	132	18	18
703	723	89	744	778	718	581	22	815	823	89	90
110	108	19	110	120	109	85	2	87	86	19	19
360	380	175	366	387	378	362	222	329	331	175	175
847	196	39	779	212	639	110	19	398	403	39	38
44	24	11	44	24	42	18	18	43	43	11	11
22.8	12.8	3.4	23.4	13.5	20.9	8.2	2.4	13.7	13.6	3.4	3.1
20	19	3	20	19	20	13	2	24	22	3	3
24	16	6	24	18	29	16	12	35	36	6	6
87	59	9	94	72	94	56	28	113	112	9	8
19	16	4	23	19	20	13	0	19	19	4	4
65	39	11	66	33	59	22	6	59	62	11	10
126	68	17	123	67	109	46	1	116	114	17	13
22	8	1	21	8	18	4	0	9	9	1	1
54	30	11	53	33	48	22	3	53	51	11	9
5	2	0	7	3	2	1	0	1	1	0	0
U is semi-quantitative at this level											
2668	1793	445	2645	1907	2468	1436	388	2306	2314	445	432
0.27	0.18	0.04	0.26	0.19	0.25	0.14	0.04	0.23	0.23	0.04	0.04
99.03	0.18	93.48	98.99	99.32	98.64	97.30	94.23	98.68	99.42	93.48	92.75
99.10	0.22	93.48	99.06	99.36	98.71	97.33	94.24	98.74	99.47	93.48	92.76
Unnormalized Trace Elements (ppm):											
45.6	30.9	13.0	39.1	32.6	52.3	26.1	24.2	44.9	42.2	13.0	12.2
91.1	42.7	16.4	84.5	50.7	82.7	35.1	16.6	86.7	85.1	16.4	17.0
23.3	15.6	9.7	22.5	15.5	23.6	14.9	9.4	27.8	28.4	9.7	7.2
158.3	90.8	26.0	154.5	97.7	147.0	70.3	21.6	196.7	194.2	26.0	25.9
785.0	807.1	99.1	830.8	869.1	801.6	648.4	24.9	910.4	919.3	99.1	100.4
119.7	118.5	21.1	120.1	131.0	119.2	93.3	2.3	94.7	93.8	21.1	20.8
425.4	449.5	206.6	433.0	458.0	446.9	428.5	262.7	389.2	390.9	206.6	206.5
1155.8	267.9	53.8	1062.8	289.4	872.0	150.3	25.8	543.4	550.6	53.8	52.2
56.3	30.4	14.0	55.6	30.4	52.7	22.4	22.4	54.7	54.2	14.0	13.5
32.6	18.3	4.9	33.5	19.3	29.9	11.7	3.4	19.6	19.5	4.9	4.4
26.6	25.3	4.3	26.5	25.1	26.6	17.2	3.2	31.6	29.0	4.3	3.9
29.8	19.7	8.0	30.3	22.5	36.8	20.3	14.9	44.3	44.6	8.0	7.5
108.8	73.3	11.6	117.4	89.9	117.6	70.4	34.7	141.3	140.4	11.6	9.4
20.1	17.3	4.6	25.1	20.5	21.5	14.1	0.0	19.9	20.7	4.6	4.2
75.6	45.6	13.3	77.2	38.3	69.0	26.3	6.7	69.4	72.2	13.3	11.3
154.5	83.0	20.3	151.0	82.5	133.7	56.3	1.0	142.6	140.3	20.3	16.0
24.3	8.4	1.0	23.4	8.4	20.1	4.1	0.0	9.6	9.9	1.0	1.2
63.5	35.1	12.5	61.5	38.0	56.5	25.3	3.6	61.2	58.9	12.5	10.5
3396	**2179**	**540**	**3349**	**2319**	**3110**	**1735**	**478**	**2888**	**2894**	**540**	**524**
0.34	**0.22**	**0.05**	**0.33**	**0.23**	**0.31**	**0.17**	**0.05**	**0.29**	**0.29**	**0.05**	**0.05**

Appendix 5 – Photographs of the Granite Basin and Limestone Basin

Photo 1. View of vegetative cover looking east along a Qft1 fan-terrace deposit in the Granite Basin.

Photo 2. View of vegetative cover on a N-facing hillslope in the Granite Basin.

Appendix 5 – Photographs of the Granite Basin and Limestone Basin cont'd

Photo 3. View of vegetative cover looking north up colluvial apron 4 in the Granite Basin.

Photo 4. View of topography and vegetative cover looking East in the Granite Basin.

Appendix 5 – Photographs of the Granite Basin and Limestone Basin cont'd

Photo 5. View looking N-across Limestone Basin.

Photo 6. View looking east from the N-facing hillslope in the Limestone Basin.

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Unburned Piñon/Juniper Tree Hillslopes	Pit #1	Interspace Tree #2	A			0-20	c.g. soil with small amounts of silt and sand, dark brown, lots of qtz. grained granitic fragments, lo., no peds, no structure
			Cr			20-70+	fractured bedrock, reddish hue, has previously been exposed to the surface, silt and sand within fractures
	Pit #2	Downslope Tree #2	C	10 YR 5/3	10 YR 3/3	0-10	c.g. sand with very little silt, dark brown, pine needles and other OM present, very little silt, lo., no peds, no structure
			A	10YR 5/4	10 YR 3/3	10-26	c.g. sand with small granitic clasts, dark brown, lo., no structure, no peds, sparse roots
			Cr			26-45+	highly fractured bedrock, larger more angular clasts than previous pit, clasts have white coating (salt?), clasts do not have red hue associated with other
	Pit #3	Interspace Tree #1	Avj			0-2	very thin silty, horizon, very weak platy structure
			A	10 YR 5/4	10 YR 3/3	2-14	very c.g. sand with small amounts of silt, lo., no peds, no structure
			Cr			14-34+	highly fractured weathered bedrock, bedrock not as weathered as Pit #1
	Pit #4	Upslope Tree #1	C			0-3	c.g. very little silt, no soil development, no peds
			AC	10 YR 5/4	10 YR 3/3	3-33	highly weathered bedrock, lots of silt and c.g. sand in interspace areas, bedrock has into small granitic pieces 2 cm3. Very easy digging, at first believed to be digging through redeposited granite, but with depth determined it was extremely weathered in situ bedrock.
			Cr1			33-70	
			Cr2			70-72+	
	Pit #5	Downslope (Tree #1)	C			0-3	granitic clasts with pine needles, roots
			O	10 YR 3/1	10 YR 2/2	3-20	c.g. sandy layer with granitic clasts, with OM mixed throughout, very wk. ped development, roots
			A1	10 YR 4/3	10 YR 3/2	20-28	thin silty layer, roots
			A2	10 YR 4/3	10 YR 3/2	28-58	c.g. layer with sand and gravels, roots, evidence of old fire - burned roots
			Cr			58-88+	grussifying bedrock, bedrock very soft and crumbly white evaporite on sides of clasts, roots, evidence of old fire - burned roots
	Pit #6	Sideslope (Tree #1)	C			0-3	granitic clasts with pine needles, roots
			O			3-8	c.g. sandy layer with granitic clasts, with OM mixed throughout, very wk. ped development, roots
			A1	10 YR 4/2	10 YR 2/2	8-26	thin silty layer, roots, week peds, lo. to s.g.
			A2	10 YR 4/4	10 YR 2/2	26-56	c.g. layer with sand and gravels, roots, slightly more structure than A1
			Cr			56-60+	grussifying bedrock, bedrock very soft and crumbly white evaporite on sides of clasts, roots

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region cont'd

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Unburned Piñon/Juniper Tree Hillslopes	Pit #7	Sideslope (Tree #2)	C	10 YR 3/2	10 YR 2/1	0-4	organic matter
			A1	10 YR 5/4	10 YR 4/4	4-10	c.g. sand and gravels with some silt, sparse roots, lo. To s.g.
			A2	10 YR 5/4	10 YR 4/4	10-24	c.g. granitic clasts with silt and sand
			Cr	10YR 6/3	10 YR 5/3	24-55+	crumbly, fractured, grussifying bedrock
	Pit #8	Upslope (Tree #2)	C			nm	OM and c.g. granitic clasts
			A1			nm	c.g. sand with silt, roots, lo.
			A2			nm	silt and c.g. sand
			Cr			nm	highly fractured bedrock
	Pit #9	Downslope (Tree #9)	C			0-10	OM, pine needles mixed with some gravels and sand
			A1			10-15	c.g. sand, decreasing gravel amounts, s.g. to lo., roots, no structure
			A2			15-20	coarse gravels with f.g. sand, minor amounts of silt, no structure, roots
			Cr			20-30+	crumbly bedrock, white hue, fractured, soils in fractures, roots throughout
	Pit #10	Sideslope (Tree #3)	C			0-8	OM with some gravels and sands
			A			8-25	sand and gravels, lo. to s.g., roots, no peds
			Cr			25-40+	grussifying bedrock, strong salt rinds, roots, wk. ped development,
	Pit #11	Upslope (Tree #3)	C			0-10	OM with abundant pine needles and c.g. gravels
			A1			10-35	gravel and sands, poorly developed, very weak peds in places
			A2			35-43	gravels and c.g. sand, some weak peds, roots
			Cr			43-50+	bedrock with sand and fines, strong salt layer, bedrock has weathered platy structure, some weak roots
	Pit #12	Interspace (Tree #2)	C			0-1	gravels with some OM
			A1	10 YR 4/4	10 YR 3/2	1-13	thin layer of gravels mixed with duff
			A2	10 YR 4/4	10 YR 3/2	13-26	gravels with c.g. sand and roots
			A3			26-45	c.g. sand and f.g. sand, roots
			AC			45-90	c.g. gravels, roots, highly weathered bedrock, charcoal layer, the charcoal layer was the surface layer at the time of the old fire, top of the roots are
			Cr			90+	highly weathered bedrock
	Pit #13	Interspace (Tree #2)	Co			0-2	gravels with OM
			A1			2-15	gravels with c.g. sand and roots, very wk. peds
			A2			15-40	same as above, with increasing gravel size, some peds, this layer has the greatest abundance of burned roots
			A3			40-50+	sparse roots, wk. peds, ash pocket

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region cont'd

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Burned Piñon/Juniper Tree Hillslopes	Pit #14	Downslope (Tree #4)	C			0-2	top layer is burned OM and soil, no roots, some structure (product of burn?)
			A			2-10	coarse grained gravel and sand, wk. peds
			C			10-30+	bedrock fractured harder than bedrock @ burned area, some roots in fractures, very small amount of silt and sand in fractures
	Pit # 15	Sideslope (Tree#4)	C			0-2	very ashy layer with OM and gravels
			A1			2-10	darkened mineral layer w/roots (sparse)
			A2			10-20	gravels and sands, light colored, lo. to s.g., wk. development, wk. peds
			Cr			20-50+	fractured bedrock, denser than Pit #14
	Pit # 16	Upslope (Tree #4)	C			0-2	burned layer, OM and gravels
			A1			2-6	thin mineral layer w/roots, lo. - s.g., wk. structure, burned
			A2			6-15	gravels and fines, roots, very cemented
			Cr			15-40+	bedrock some fractures, roots
	Pit #17	Interspace (Tree #4)	C			0-2	burned OM w/gravels; OM deposited from upslope
			A1			2-15	burned mineral horizon, roots, gravel and sand, lo. to sag., the burned layer is much thicker than previous burned layers
			A2			15-27	gravelly sand, some ash possibly from translocation, roots, ped development
			Cr			27-40+	bedrock, fractured, fully rotting in some places, roots
	Pit #18	Downslope (Tree #5)	C			0-2	burned OM w/gravels; OM deposited from upslope
			A1	10 YR 3/2	10 YR 2/2	2-6	burned mineral horizon, roots, gravel and sand, lo. to sag., wk. peds., the burned layer is much thicker than previous burned layers
			A2	10 YR 4/3	10 YR 3/2	6-15	very gravely layer, roots, mod. peds, s.g., did not seem as cohesive as previous A2 layers
			Cr			15-45	sapprolitic layer, clay rich, red, wk. roots
			Cr			45-50+	grussifying bedrock, fractured
	Pit #19	Sideslope (Tree #5)	C			0-1	gravels and OM, burned
			A1	10 YR 3/2	10 YR 2/2	1-4	sand and silt, dark brown, wk., no structure, lo. to s.g.
			A2	10 YR 4/3	10 YR 3/2	4-16	gravels and sand, lo., wk. to mod. ped development
			Cr			16-50+	sapprolitic granite, abundant roots, one lg. root which likely helps stabilize sediment at this location
	Pit #20	Upslope (Tree #5)	C			0-1	gravels with very sparse amounts of OM
			A1			1-5	f.g. sand, wk. roots, burned
			A2			5-24	gravel rich w/increasing amounts of roots, s.g., mod. peds, variable structure
			Cr			24-40+	sapprolite

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region cont'd

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Burned Piñon/Juniper Tree Hillslopes	Pit #21	Interspace (Tree# 5)	C			0-1	gravels
			A1			1-5	v.f.g., lo. to s.g., some structure, wk. to no evidence of a burn, wk. roots
			A2			5-12	gravel rich, light brown, wk. soil development, roots
			Cr			12-15+	bedrock, sapprolitic in places
	Pit #22	Downslope (Tree #6)	C			0-1	gravel and OM, burned, similar to other canopy horizons
			A1	10 YR 4/2	10 YR 3/2	1-6	f.g., slightly burned, lo., some peds
			A2	10 YR 5/3	10 YR 4/3	6-15	c.g. gravels, cohesive, mod. peds, reddish hue
			Cr			15-40+	sapprolitic
	Pit #23	Sideslope (Tree #6)	C	10 YR 2/1	10 YR 2/1	0-1	burned gravel and OM
			A1	10 YR 4/2	10 YR 3/2	1-5	f.g. sand, sparse roots (burned), peds in places
			A2	10 YR 5/4	10 YR 3/3	5-15	c.g. gravels and sand, less gravels than in other pits
			Cr	10 YR 6/3	10 YR 5/3	15-40+	sapprolitic
	Pit #24	Upslope (Tree #6)	C			0-1	burned gravel and OM
			A1	10 YR 4/2	10 YR 3/3	1-4	f.g. burned layer, wk. to no structure, sparse roots
			A2	10 YR 5/3	10 YR 3/3	4-9	gravelly layer w/ped development
			Cr			9-15+	highly fractured bedrock
	Pit #25	Interspace (Tree #6)	C			0-1	gravels and weak OM
			A1	10 YR 4/2	10 YR 3/3	1-7	slightly burned mineral layer, wk. roots, gravels, not as f.g. as the A1 horizon around Tree #6, wk. development
			A2	10 YR 5/3	10 YR 3/3	7-15	very gravelly, mod. peds, fine roots
			Cr			15-30+	sapprolite and fractured bedrock

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Burned Yucca/Joshua Tree Hillslopes	Pit #26	Downslope (Tree #7)	C			0-1	burned gravel layer
			A1			1-10	burned, very loose sandy gravel, roots, wk. to no peds, s.g. to loose
			A2			10-26	f.g. sand w/angular gravels, s.g., wk. peds
			AC			26-35+	angular clasts w/pockets of sapprolite and sand grains, red hue, sapprolite is not as strong as in the pinyon/juniper burn site
	Pit #27	Sideslope (Tree #7)	C	10 YR 4/2	10 YR 2/2	0-1	burned gravel layer
			A1	10 YR 4/3	10 YR 2/1	1-7	sand and gravels, lo., roots, wk. peds, burned
			A2	10 YR 5/3	10 YR 3/2	7-15	angular clasts w/sand and gravels, roots, some wk. peds
			AC	10 YR 4/3	10 YR 4/3	15-30+	angular clasts w/pockets of sapprolite and sand grains, red hue, sapprolite is not as strong as in the pinyon/juniper burn site
	Pit #28	Upslope (Tree #7)	C			0-1	burned gravel layer
			A1			1-7	sand and gravels, lo., roots, wk. peds, burned
			A2			7-15	angular clasts w/sand and gravels, roots, some wk. peds
			AC			15-30+	angular clasts w/pockets of sapprolite and sand grains, red hue, sapprolite is not as strong as in the pinyon/juniper burn site
	Pit #29	Interspace (Tree #7)	C			0-1	gravel and OM burned
			A1			1-6	c.g. sand and gravels, some structure, burned
			A2			6-15	c.g. sand w/angular clasts, s.g. to lo., some ped development
			AC			15-30+	angular clasts w/pockets of sapprolite and sand grains, red hue, sapprolite is not as strong as in the pinyon/juniper burn site
	Pit #30	Downslope (Tree #8)	C			0-1	gravel and OM burned
			A	10 YR 5/3	10 YR 3/3	1-5	sandy burned layer w/some c.g. gravels , some soil development, wk. ped structure, roots
			AC	10 YR 4/2	10 YR 3/3	5-15	sand and gravels, abundant angular clasts, roots, lo., reddish hue
			C			15-30+	sand and gravels, abundant angular clasts, roots, lo.

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region cont'd

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Burned Yucca/Joshua Tree Hillslopes	Pit #31	Sideslope (Tree #8)	C			0-1	gravel and OM burned
			A	10 YR 4/3	10 YR 3/2	1-5	sandy burned layer w/some c.g. gravels , some soil development, wk. ped structure, roots
			AC	10 YR 4/4	10 YR 3/3	5-15	sand and gravels, abundant angular clasts, roots, lo., reddish hue
			C			15-30+	sand and gravels, abundant angular clasts, roots, lo.
	Pit #32	Upslope (Tree #8)	C			0-1	gravel and OM burned
			A			1-5	sandy burned layer w/some c.g. gravels , some soil development, wk. ped structure, roots
			AC			5-15	sand and gravels, abundant angular clasts, roots, lo., reddish hue
			C			15-30+	sand and gravels, abundant angular clasts, roots, lo.
	Pit #33	Interspace (Tree #8)	C			0-1	gravel layer w/angular clasts
			A			1-12	c.g. sands and angular gravels, lo. to mod. peds, angular clasts
			AC			12-25+	angular clasts, roots, red grussifying granite
	Pit #34	Downslope 9 (Tree #9)	C			0-2	burned OM and gravels
			A1	10 YR 2/2	10 YR 2/1	2-5	burned A horizon, roots, lo., wk. structure
			A2	10 YR 4/4	10 YR 3/4	5-9	c.g. sand and gravels, slightly burned roots, ash (from translocation?)
			Cr			9-25+	grussifying bedrock, very red
	Pit #35	Sideslope (Tree #9)	C			0-1	gravels w/some OM, slightly burned
			A	10 YR 5/3	10 YR 3/2	1-7	silt and gravels, slightly burned, lo., very wk. peds
			Cr			7-25+	grussifying bedrock, very red
	Pit #36	Upslope (Tree #9)	C			0-1	gravels w/wk. OM, slightly burned
			A1	10 YR 5/3	10 YR 3/1	1-4	silt and gravels, slightly burned, lo., very wk. peds
			A2	10 YR 4/3	10 YR 3/3	4-10	silt and gravels, slightly burned, lo., very wk. peds
			Cr			10-40+	grussifying bedrock, very red
	Pit #37	Interspace (Tree #9)	Co			0-1	gravels w/wk. to no OM
			A1	10 YR 4/4	10 YR 4/3	n.m.	thin silt layer, w/wk. platy structure, roots
			A2			n.m.	lo. to s.g., wk. peds, roots
			Cr			n.m.	grussifying bedrock, very red

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region cont'd

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Unburned Yucca/Joshua Tree Hillslopes	Pit #38	Downslope (Tree #10)	C			0-1	1cm^2 gravels w/ OM
			A1	10 YR 5/3	10 YR 3/2	1-5	c.g. sand and gravels, lo., very wk. peds, no development, roots
			A2			5-12	gravels w/increasing amounts of fines, some peds, roots, wk. development
			AC			12-30+	gravels w/semi-angular w'd bedrock,, roots, slightly reddish hue
	Pit # 39	Sideslope (Tree #10)	C			0-1	1cm^2 gravels w/ OM
			A1			1-5	c.g. sand and gravels, lo., very wk. peds, no development, roots
			A2			5-20	angular weathered clasts, gravels, roots
			AC			20-30+	grussifying bedrock
	Pit #40	Upslope (Tree #10)	C			0-1	gravels w/OM
			A1			1-4	c.g. sand and gravels, lo., very wk. peds, no development, roots
			A2			4-20	thick layer of fine grained sediment w/gravels, a few angular clasts, roots
			AC			20-30+	a mixture of fines and gravels w/angular clasts and potentially some grussifying granite, roots, some peds
	Pit #41	Interspace (Tree #10)	C			0-1	gravels w/OM
			A1			1-8	c.g. sand and gravels, lo., very wk. peds, no development, roots
			A2			8-15	thick layer of fine grained sediment w/gravels, a few angular clasts, roots
			AC			15-30+	grussifying bedrock, angular clasts, dominantly bedrock
	Pit #42	Downslope (Tree #11)	C			0-1	gravels and OM, more OM than previously observed at this site
			A1	10 YR 5/3	10 YR 4/2	1-7	c.g. sand and gravels, very lo., unconsolidated, some peds, roots
			A2	10 YR 5/3	10 YR 4/2	7-26	c.g. sand and gravels, lo., very wk. peds, roots
			AC			26-50+	similar to A2 w/increasing amounts of angular clasts, roots
	Pit #43	Sideslope (Tree # 11)	C	10 YR 5/3	10 YR 3/2	0-1	gravels and OM, more OM than previously observed at this site
			A1	10 YR 5/3	10 YR 3/2	1-9	c.g. sand and gravels, very lo., unconsolidated, some peds, roots
			A2	10 YR 5/3	10 YR 3/2	9-21	c.g. sand and gravels, lo., very wk. peds, roots
			AC	10 YR 5/3	10 YR 3/2	21-30+	similar to A2 w/increasing amounts of angular clasts, roots
	Pit #44	Upslope (Tree #11)	C			0-1	gravels and OM, more OM than previously observed at this site
			A1			1-6	c.g. sand and gravels, very lo., unconsolidated, some peds, roots
			A2			6-15	c.g. sand and gravels, lo., very wk. peds, roots
			AC			15-30+	similar to A2 w/increasing amounts of angular clasts, roots

Appendix 6 – Field Soil Descriptions for the for the Mid Hills Region cont'd

Field site	Field ID	Pit location	Horizons	Colors		Depth	Notes
				dry	wet	b.g.s.	
Unburned Yucca/Joshua Tree Hillslopes	Pit #45	Interspace (Tree #11)	C			0-1	gravels and very wk. OM
			A1			1-7	c.g. sand and gravels, very lo., unconsolidated, some peds, roots
			A2			7-13	c.g. sand and gravels, lo., very wk. peds, roots
			AC			13-20+	grussifying granite
	Pit #46	Downslope (Tree #12)	C	10 YR 5/4	10 YR 3/2	0-1	gravels w/OM, larger surface gravels than in other areas of site-approaching fist size
			A1	10 YR 5/4	10 YR 3/2	1-10	gravels, lo., wk. to no peds, roots
			A2			10-2	gravels, lo., wk. to no peds, sparse roots
			AC			20-35+	grussifying granite and angular clast, roots
	Pit #47	Sideslope (Tree #12)	C			0-1	gravels w/OM, larger surface gravels than in other areas of site-approaching fist size
			A1	10 YR 5/2	10 YR 3/2	1-5	gravels, lo., wk. to no peds, roots
			A2			5-40	gravels, lo., wk. to no peds, sparse roots
			AC			40-50+	grussifying granite and angular clast, roots
	Pit #48	Upslope (Tree #12)	C			0-1	gravels w/OM, larger surface gravels than in other areas of site-approaching fist size
			A1	10 YR 5/3	10 YR 3/2	1-5	gravels, lo., wk. to no peds, roots
			A2	10 YR 5/3	10 YR 3/3	5-25	gravels, lo., wk. to no peds, sparse roots
			AC			25-35+	grussifying granite and angular clast, roots
	Pit #49	Interspace (Tree #13)	C			0-1	gravels and OM
			A1	10 YR 3/5	10 YR 3/2	1-8	gravels, lo., wk. to no peds, roots
			A2	10 YR 5/3	10 YR 3/3	8-25	gravels, lo., wk. to no peds, sparse roots
			A3			25-40	same as A2, but less indurated, lo., wk. peds
			AC			40-50+	angular clasts w/some f.g. sand

Appendix 7 – Laboratory Results for Particle Size Distribution and Fine Organic Matter Content of the Soils in the Mid Hills

Site	Field ID	Soil Pit Location	Horizon Thickness (cm)	Soil Moisture (g/g)	% wt. Gravel	Particle Size Distribution of < 2 mm fraction								% Organic matter
						>62.5 um	SILT 15 um	SILT 3 um	CLAY <3 um	sand	fines	gravel	total	
Pinon-Juniper Unburned	Pit #1 0-20 cm	Interspace	20	0.006673	62.35							62.35	62.35	3.10
	Pit #1 20-70		50	0.013293	65.89	72.92	10.76	9.53	6.81	24.87	9.25	65.89	100.01	2.82
	Pit #1 Bedrock		C Horizon											
	Pit #2 Downslope (surface)	Down slope	2	0.015995	68.09							68.09	68.09	10.68
	Pit #2 0-10 cm		10	0.013955	32.97	76.00	12.30	8.45	3.25	50.94	16.09	32.97	100.00	3.53
	Pit# 2 10-26		16	0.013518	46.41	71.87	13.11	10.31	4.74	38.51	15.09	46.41	100.02	1.95
	Pit #2 26-45		C Horizon											
	Pit #3 0-2	Interspace	2	0.005559	51.07							51.07	51.07	1.67
	Pit #3 2-14		12	0.004732	63.51	74.64	10.44	8.80	6.12	27.23	9.25	63.51	100.00	2.19
	Pit #3 14-34		C Horizon	0.001742										0.40
	Pit #4 unit 0	Upslope	3	0.002986	95.13							95.13	95.13	23.00
	Pit #4 unit 1		30	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
	Pit #4 unit 2		37	0.003265	79.63	75.19	11.48	8.41	4.95	15.32	5.06	79.63	100.01	2.30
	Pit #4 unit 3		C Horizon											
	Pit #4 unit 4		C Horizon											
	Pit #5 unit 1	Down slope	3	0.012757	87.63							87.63	87.63	20.09
	Pit #5 unit 2		17	0.019784	60.11	80.37	9.98	7.10	2.55	32.06	7.83	60.11	100.00	8.36
	Pit #5 unit 3		8	0.01235	55.30	70.82	14.27	9.96	4.98	31.66	13.05	55.30	100.01	8.26
	Pit #5 unit 4		30											
	Pit #5 unit 5		C Horizon											
	Pit #6 unit 1	Side slope	3	0.008533	85.15							85.15	85.15	22.57
	Pit #6 unit 2		5	0.007559	64.12	73.89	12.82	9.11	4.14	26.51	9.36	64.12	99.99	4.51
	Pit #6 unit 3		18	-0.07737	63.97	72.04	13.73	9.60	4.60	25.96	10.06	63.97	99.99	2.17
	Pit #6 unit 4		C Horizon											
	Pit # 7 unit 1	Side slope	4	0.013658	40.19							40.19	40.19	10.23
	Pit # 7 unit 2		6	0.009113	34.42	77.16	10.57	8.12	4.17	50.60	14.99	34.42	100.02	3.10
	Pit # 7 unit 3		14	0.004842	n.m.	76.55	10.26	8.54	4.64	49.06	15.03	35.92	100.00	1.70
	Pit # 7 unit 4		C Horizon											
	Pit #8 unit #1	Upslope	3	0.005714	47.85							47.85	47.85	4.03
	Pit #8 unit #2		10	0.004069	65.71	78.38	11.14	6.96	3.49	26.88	7.41	65.71	99.99	5.11
	Pit #8 unit #3		15	0.007302	60.76	78.49	9.58	7.31	4.62	30.80	8.44	60.76	100.00	2.08
	Pit #8 unit #4		C Horizon											
	Pit #9 unit 1	Down slope	9	0.028505	35.12							35.12	35.12	7.72
	Pit #9 unit 2		5	0.013446	45.40	72.39	11.38	10.11	6.09	39.52	15.06	45.40	99.98	3.06
	Pit #9 unit 3		5	0.012967	52.47	68.66	14.03	11.03	6.31	32.63	14.91	52.47	100.02	2.51
	Pit #9 unit 4		C Horizon	0.009759										1.72
	Pit #10 unit 1	Side slope	8	0.009854	56.35							56.35	56.35	4.99
	Pit #10 unit 2		17	0.011823	59.64	69.49	13.55	11.02	5.93	28.05	12.32	59.64	100.00	2.97
	Pit #10 unit 3		15	0.012687	62.49	67.05	14.24	11.69	7.02	25.15	12.36	62.49	100.00	3.02
	Pit #11 unit 1	Upslope	10	0.010082										3.35
	Pit #11 unit 2		15	0.120255	53.09	73.11	11.36	9.59	5.94	34.29	12.61	53.09	100.00	2.12
	Pit #11 unit 3		8	0.014038	60.42	71.45	11.69	10.58	6.28	28.28	11.30	60.42	100.00	2.57
	Pit #12 unit 1	Interspace	1	0.003323	72.78							72.78	72.78	3.50
	Pit #12 unit 2		12	0.005506	59.02	76.56	11.20	8.04	4.19	31.38	9.60	59.02	100.00	1.95
	Pit #12 unit 3		13	0.010937	57.75	78.17	10.09	7.63	4.11	33.03	9.22	57.75	100.00	1.45
	Pit #12 unit 4		19											
	Pit #12 unit 5		45											
	Pit #12 unit 6		C Horizon											
	Pit #13 unit 1	Interspace	2	0.004475	56.41							56.41	56.41	2.62
	Pit #13 unit 2		13	0.005318	76.59	74.42	13.50	8.14	3.91	17.42	5.98	76.59	99.99	4.71
	Pit #13 unit 3		35	0.01164	59.66	75.46	11.91	8.05	4.58	30.44	9.90	59.66	100.00	2.05
	Pit #13 unit 4		10											

- indicates no data

Lab ID # - from DRI soil lab

Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface

g g^{-1} – indicating grams/grams

Appendix 7 – Laboratory Results for Particle Size Distribution and Fine Organic Matter Content of the Soils in the Mid Hills cont'd

Site	Field ID	Soil Pit Location	Horizon Thickness (cm)	Soil Moisture (g/g)	% wt. Gravel	Particle Size Distribution of < 2 mm fraction								% Organic matter
						>62.5 um	SILT 15 um	SILT 3 um	CLAY <3 um	sand	fines	gravel	total	
	Pit #14 unit 1	Down slope	2	0.006926	47.98							47.98	47.98	2.60
	Pit #14 unit 2		8	0.006814	60.44	63.46	12.77	13.39	10.42	25.11	14.47	60.44	100.02	3.15
	Pit #14 unit 3		C Horizon											0.40
	Pit #15 unit 1	Side slope	2	0.008105	46.75							46.75	46.75	4.78
	Pit #15 unit 2		5	0.015785	16.80	71.33	16.27	8.45	3.94	59.35	23.85	16.80	100.00	6.30
	Pit #15 unit 3		13	0.014632	37.76	60.29	13.38	15.20	11.10	37.52	24.69	37.76	99.97	2.25
	Pit #15 unit 4		C Horizon											
	Pit #16 unit 1	Upslope	2	0.0077	44.25							44.25	44.25	5.24
	Pit #16 unit 2		4	0.011171	27.43	65.73	16.86	11.67	5.70	47.70	24.84	27.43	99.97	6.55
	Pit #16 unit 3		9		60.42	62.24	15.81	13.94	8.01	24.63	14.95	60.42	100.00	3.69
	Pit #16 unit 4		C Horizon											
	Pit #17 unit 1	Interspace	2	0.013468	13.86							13.86	13.86	8.12
	Pit #17 unit 2		13	0.019765	34.71	73.92	13.54	8.48	4.06	48.26	17.03	34.71	100.00	11.13
	Pit #17 unit 3		12	-0.02744	48.29	62.56	15.35	13.71	8.38	32.35	19.36	48.29	100.00	3.04
P	Pit #17 unit 4		C Horizon											
i	Pit #18 unit 1	Down slope	2	0.018027	36.21							36.21	36.21	8.87
n	Pit #18 unit 2		4	0.016984	11.70	65.27	19.16	10.53	5.03	57.63	30.66	11.70	100.00	5.40
o	Pit #18 unit 3		9	0.009263	44.42	66.89	13.43	12.13	7.55	37.18	18.40	44.42	100.00	2.68
n	Pit #18 unit 4		C Horizon											
-	Pit #18 unit 5		C Horizon											
J	Pit #19 unit 1	Side slope	1	0.004222	57.83							57.83	57.83	2.45
u	Pit #19 unit 2		3	0.008336	18.09	66.20	17.07	10.95	5.79	54.22	27.69	18.09	100.00	2.28
n	Pit #19 unit 3		12	0.008308	36.48	61.98	16.44	13.24	8.30	39.37	24.13	36.48	99.97	2.08
i	Pit #19 unit 4		C Horizon											
p	Pit #20 unit 1	Upslope	1	0.002543	60.78							60.78	60.78	2.94
e	Pit #20 unit 2		4	0.006337	33.53	73.21	12.49	9.44	4.85	48.67	17.80	33.53	100.00	3.44
r	Pit #20 unit 3		19	0.011847	42.22	67.51	12.65	11.83	8.04	39.01	18.79	42.22	100.02	2.20
	Pit #20 unit 4		C Horizon											
B	Pit# 21 unit 1	Interspace	1	0.00231	75.58							75.58	75.58	2.87
u	Pit# 21 unit 2		4	0.004007	38.47	69.79	14.40	9.76	6.08	42.94	18.61	38.47	100.02	2.19
r	Pit# 21 unit 3		7	0.005748	67.96	52.04	16.61	16.91	14.40	16.67	15.35	67.96	99.98	2.88
n	Pit# 21 unit 4		C Horizon											
e	Pit #22 unit 1	Down slope	1	0.00838	46.58							46.58	46.58	2.39
d	Pit #22 unit 2		5	0.010961	22.80	64.43	17.06	12.25	6.26	49.74	27.46	22.80	100.00	2.45
	Pit #22 unit 3		9	0.012857	37.71	57.41	14.11	17.39	11.09	35.76	26.53	37.71	100.00	1.81
	Pit #22 unit 4		C Horizon											
	Pit #23 unit 1	Side slope	1	0.00849	66.62							66.62	66.62	7.41
	Pit #23 unit 2		4	0.008957	41.57	74.42	13.54	8.50	3.55	43.49	14.95	41.57	100.00	3.50
	Pit #23 unit 3		10	0.008668	40.38	65.01	15.89	12.33	6.77	38.76	20.86	40.38	100.00	1.80
	Pit #23 unit 4		C Horizon											4.13
	Pit #24 unit 1	Upslope	1	0.002352	67.85							67.85	67.85	3.89
	Pit #24 unit 2		3	0.00365	41.27	70.06	16.43	9.24	4.27	41.15	17.59	41.27	100.00	3.35
	Pit #24 unit 3		5	0.004991	50.01	66.38	16.96	11.07	5.63	33.19	16.83	50.01	100.02	2.09
	Pit #24 unit 4		C Horizon											
	Pit #25 unit 1	Interspace	1	0.005952	60.02							60.02	60.02	4.07
	Pit #25 unit 2		6	0.007151	42.54	69.63	13.40	11.07	5.90	40.01	17.45	42.54	100.00	2.57
	Pit #25 unit 3		8	0.006259	49.88	62.57	0.00	0.00	0.00	31.36	0.00	49.88	81.24	2.28
	Pit #25 unit 4		C Horizon											

- indicates no data

Lab ID # - from DRI soil lab

Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface

g g^{-1} – indicating grams/grams

Appendix 7 – Laboratory Results for Particle Size Distribution and Fine Organic Matter Content of the Soils in the Mid Hills cont'd

Site	Field ID	Soil Pit Location	Horizon Thickness (cm)	Soil Moisture (g/g)	% wt. Gravel	Particle Size Distribution of < 2 mm fraction >62.5 um	SILT 15 um	SILT 3 um	CLAY <3 um	sand	fines	gravel	total	% Organic matter
Yucca-Blackbrush Burned	Pit #26 unit 1	Down slope	1	0.005194	65.74							65.74	65.74	4.30
	Pit #26 unit 2		9	0.012053	25.38	68.85	14.16	10.75	6.20	51.38	23.22	25.38	99.97	2.64
	Pit #26 unit 3		16	0.09575	41.96	64.37	13.69	13.19	8.75	37.36	20.68	41.96	100.00	1.48
	Pit #26 unit 4		C Horizon	0.021174										1.49
	Pit #27 unit 1	Side slope	1	0.004217	50.97							50.97	50.97	3.51
	Pit #27 unit 2		4	0.007247	14.61	71.18	13.52	9.78	5.51	60.79	24.61	14.61	100.00	3.95
	Pit #27 unit 3		18	0.010363	43.21	63.28	14.75	12.85	9.08	35.93	20.83	43.21	99.98	2.58
	Pit #27 unit 4		AC Horizon	0.00156	70.91							70.91	70.91	
	Pit #28 unit 1	Upslope	1	0.002759	42.70							42.70	42.70	2.25
	Pit #28 unit 2		6	0.006428	38.11	70.62	12.84	9.78	6.76	43.71	18.18	38.11	100.00	2.23
	Pit #28 unit 3		8	0.018564	40.86	65.42	13.16	12.00	9.42	38.69	20.45	40.86	100.00	2.12
	Pit #28 unit 4		C Horizon	0.001552	69.49	61.24	14.13	13.67	10.95	18.69	11.83	69.49	100.00	2.65
	Pit #29 unit 1	Interspace	1	0.003923	37.97							37.97	37.97	2.22
	Pit #29 unit 2		5	0.012173	45.07	68.99	14.94	10.02	6.06	37.90	17.04	45.07	100.00	2.32
	Pit #29 unit 3		24	0.005343	52.34	67.84	12.16	10.87	9.12	32.33	15.32	52.34	100.00	2.14
	Pit #30 unit 1	Down slope	0.5	0.008445	44.92							44.92	44.92	n.m.
	Pit #30 unit 2		4.5	0.010746	70.53	69.36	12.47	10.80	7.34	20.44	9.02	70.53	99.99	5.78
	Pit #30 unit 3		10	0.010746	22.12	72.13	13.18	9.59	5.10	56.18	21.70	22.12	100.00	3.47
	Pit #30 unit 4		C Horizon											
	Pit #31 unit 1	Side slope	0.5	0.002688	77.82							77.82	77.82	2.11
	Pit #31 unit 2		4.5	0.009298	24.06	72.29	13.38	9.24	5.09	54.90	21.04	24.06	100.00	2.38
	Pit #31 unit 3		10	0.005913	56.91	72.61	11.23	9.52	6.65	31.29	11.80	56.91	100.00	1.40
	Pit #31 unit 4		C Horizon											
	Pit #32 unit 1	Upslope	0.5	0.001959	48.04							48.04	48.04	1.96
	Pit #32 unit 2		4.5	0.001702	30.95	75.07	11.83	8.21	4.87	51.83	17.20	30.95	99.98	2.09
	Pit #32 unit 3		10	0.005408	47.55	70.86	10.89	10.63	7.62	37.17	15.28	47.55	100.00	1.64
	Pit #32 unit 4		C Horizon	0.012865	38.83	70.64	9.96	10.87	8.50	43.21	17.94	38.83	99.98	1.92
	Pit #33 unit 1	Interspace	1	0.001368	79.88							79.88	79.88	1.86
	Pit #33 unit 2		11	0.005595	30.70	72.14	11.55	9.64	6.67	49.99	19.31	30.70	100.00	1.65
	Pit #33 unit 3		13	0.008546	54.17	75.81	8.18	8.98	7.00	34.75	11.07	54.17	99.99	1.87
	Pit #34 unit 1	Down slope	2	0.005502	37.74							37.74	37.74	n.m.
	Pit #34 unit 2		3	0.006599	26.98	73.12	11.42	9.72	5.74	53.39	19.63	26.98	100.00	2.14
	Pit #34 unit 3		4	0.009073	38.85	71.96	9.56	10.52	7.96	44.00	17.15	38.85	100.00	1.97
	Pit #35 unit 1	Side slope	1	0.005129	45.87							45.87	45.87	2.87
	Pit #35 unit 2		6	0.010389	21.50	66.55	12.18	12.65	8.66	52.24	26.29	21.50	100.03	1.71
	Pit #36 unit 1	Upslope	1	0.005364	42.42							42.42	42.42	2.03
	Pit #36 unit 2		3	0.007146	26.28	74.64	11.11	9.01	5.25	55.02	18.70	26.28	100.00	1.78
	Pit #36 unit 3		6	0.009825	32.43	64.48	14.33	12.91	8.31	43.57	24.02	32.43	100.03	1.80
	Pit #37 unit 1	Interspace	1	0.004427	47.37							47.37	47.37	1.79
	Pit #37 unit 2		11	0.007882	35.94	71.23	10.92	10.69	7.16	45.63	18.43	35.94	100.00	1.63
	Pit #37 unit 3		13	0.012488	34.49	66.66	11.57	12.08	9.69	43.67	21.84	34.49	100.00	5.67

- indicates no data

Lab ID # - from DRI soil lab

Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface

g g^{-1} – indicating grams/grams

Appendix 7 – Laboratory Results for Particle Size Distribution and Fine Organic Matter Content of the Soils in the Mid Hills cont'd

Site	Field ID	Soil Pit Location	Horizon Thickness (cm)	Soil Moisture (g/g)	% wt. Gravel	Particle Size Distribution of < 2 mm fraction >62.5 um	SILT 15 um	SILT 3 um	CLAY <3 um	sand	fines	gravel	total	% Organic matter
Yucca-Blackbrush Unburned	Pit #38 unit 1	Down slope	1	0.003039	80.09							80.09	80.09	1.88
	Pit #38 unit 2		4	0.006053	40.52	74.58	11.20	9.07	5.18	44.36	15.14	40.52	100.02	0.18
	Pit #38 unit 4		7	0.003555	30.00	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
	Pit #39 unit 1	Side slope	1	0.002223	63.24							63.24	63.24	2.38
	Pit #39 unit 2		4	0.00533	31.58	72.17	12.75	9.22	5.83	49.37	19.02	31.58	99.98	1.84
	Pit #39 unit 3		15	0.008885	49.68	74.59	10.85	9.36	5.20	37.53	12.78	49.68	100.00	3.45
	Pit #39 unit 4		C Horizon											
	Pit #40 unit 1	Upslope	1	0.002168	67.74							67.74	67.74	4.77
	Pit #40 unit 2		3	0.002727	55.48	75.37	12.27	7.74	4.58	33.56	10.95	55.48	99.99	2.15
	Pit #40 unit 3		16	0.004871	56.20	75.88	11.09	7.86	5.20	33.23	10.58	56.20	100.01	1.57
	Pit #40 unit 4		AC Horizon											
	Pit #41 unit 1	Interspace	1	0.001228	76.01							76.01	76.01	3.42
	Pit #41 unit 2		7	0.003898	40.96	74.84	12.85	7.85	4.46	44.18	14.86	40.96	100.00	1.66
	Pit #41 unit 3		7	0.005911	41.03	70.81	12.71	10.14	6.37	41.76	17.23	41.03	100.02	1.88
	Pit #42 unit 1	Down slope	1	0.006694	54.43							54.43	54.43	2.06
	Pit #42 unit 2		6	0.010395	28.08	73.84	10.63	9.60	5.95	53.11	18.83	28.08	100.02	1.86
	Pit #42 unit 3		13	0.011787	37.67	69.46	12.50	11.11	6.89	43.30	19.01	37.67	99.98	1.57
	Pit #42 unit 4		AC Horizon	0.007175										0.92
	Pit #43 unit 1	Side slope	1	0.0115	57.74							57.74	57.74	2.47
	Pit #43 unit 2		8	0.007019	45.21	71.83	12.10	10.45	5.63	39.36	15.44	45.21	100.00	2.10
	Pit #43 unit 3		12	0.00837	41.94	71.92	11.84	10.07	6.17	41.76	16.30	41.94	100.00	1.39
	Pit #43 unit 4		AC Horizon											1.87
	Pit #44 unit 1	Upslope	1	0.002982	66.44							66.44	66.44	2.92
	Pit #44 unit 2		5	0.003557	40.79	74.83	11.24	8.51	5.42	44.31	14.90	40.79	100.00	2.10
	Pit #44 unit 3		9	0.004558	47.02	72.62	11.59	9.54	6.22	38.47	14.49	47.02	99.98	2.32
	Pit #44 unit 4		AC Horizon											
	Pit #45 unit 1	Interspace	1	0.000374	73.26							73.26	73.26	2.36
	Pit #45 unit 2		6	0.00261	31.82	74.01	12.08	8.44	5.47	50.45	17.72	31.82	100.00	2.04
	Pit #45 unit 3		6	0.005354	40.13	72.51	11.10	9.55	6.86	43.41	16.47	40.13	100.02	1.89
	Pit #46 unit 1	Down slope	1	0.00386	61.30							61.30	61.30	4.25
	Pit #46 unit 2		9	0.005125	47.75	70.33	13.73	9.81	6.13	36.75	15.50	47.75	100.00	1.89
	Pit #46 unit 3		10	0.008268	46.52	66.62	15.28	11.32	6.78	35.63	17.85	46.52	100.00	1.84
	Pit #46 unit 4		AC Horizon											
	Pit #47 unit 1	Side slope	1	0.00258	69.90							69.90	69.90	2.73
	Pit #47 unit 2		4	0.004581	47.15	74.50	11.96	8.46	5.07	39.38	13.47	47.15	100.00	1.42
	Pit #47 unit 3		35	0.009816	35.71	61.55	17.94	13.00	7.51	39.56	24.72	35.71	100.00	1.90
	Pit #47 unit 4		AC Horizon											
	Pit #48 unit 1	Upslope	1	0.001997	61.26							61.26	61.26	3.53
	Pit #48 unit 2		4	0.003437	42.49	74.65	12.84	7.75	4.75	42.94	14.58	42.49	100.00	2.12
	Pit #48 unit 3		20	0.004397	48.87	71.14	13.64	9.07	6.12	36.38	14.74	48.87	99.98	1.73
	Pit #48 unit 4		AC Horizon											
	Pit #49 unit 1	Interspace	1	0.002367	67.61							67.61	67.61	3.90
	Pit #49 unit 2		7	0.005017	41.78	76.41	10.24	8.28	5.07	44.49	13.74	41.78	100.00	1.53
	Pit #49 unit 3		17	0.005332	43.10	73.51	11.90	8.65	5.92	41.83	15.06	43.10	99.98	1.61
	Pit #49 unit 4		AC Horizon											

- indicates no data

Lab ID # - from DRI soil lab

Field ID - ID assigned in field; when field ID includes an @ sign followed by a number it is indicating depth of horizon, below the ground surface

g g^{-1} – indicating grams/grams

Appendix 8 – Mound Height, Width, and Length Measurements on Hillslopes in Mid Hills region

Pinyon-Juniper Unburned

Plant	L (cm)	W (cm)	H (cm)	
			E. side of tree	W. side of tree
1	70	100	9	
2	100	150	10	8
3	60	60	9	17
4	75	30	9	12
5	75	40	9.5	5
6	45	30	7	8
7	30	30	7	8
8	150	100	10	10

Pinyon-Juniper Burned

Plant	L (cm)	W (cm)	H (cm)		burnline on tree
			E. side of tree	W. side of tree	below surface (cm)
A	200	150	15	15	15
B	175	200	22	22	15
C	175	200	2	2	15
D	100	150	20	20	10
E	150	125	20	20	10
F	175	150	20	20	10
G	175	150	20	20	15
H	150	100	10	10	10

Yucca-Blacbrush unburned

Plant	L (cm)	W (cm)	H (cm)	
			E. side of tree	W. side of tree
1	16	30	6	6
2	26	18	7	3
3	14	12	6	2
4	24	31	7	6
5	30	75	7	8
6	35	60	7	6
7	10	14	7	5
8	7	16	7	4
9	60	65	7	9

Yucca-Blacbrush Unburned

Plant	L (cm)	W (cm)	H (cm)		burnline on tree
			E. side of tree	W. side of tree	below surface (cm)
1	34	36	3	5	1
2	43	38	12	6	1
3	40	40	5	4	1
4	45	60	5	3	1
5	35	60	2	2	0
7	25	35	4	3	2
8	30	40	4	3	1
9	45	60	3	3	1
10	40	30	5	4	0
11	30	60	4	3	3
13	50	60	4	3	3

L – length of mound
W – width of mound
H – height of mound

Appendix 9 – Rill Measurements

Unburned piñon-juniper hillslope

Rill #1

Location of measurment on transect (cm)	Depth to surface from transect line (cm)		
	Bottom	Middle	Top
0	6	0	5
10	8	0	6
20	12	1	10
30	15	5	14
40	16	7	15
50	23	7	17
60	20	10	18
70	23	11	20
80	20	16	22
90	17	20	27
100	13	30	32
110	10	31	35
120	10	34	35
130	7	38	35
140	5	40	37
150	3	43	35
160	3	44	30
170		47	25
180		42	21
190		36	18
200		33	16
210		28	15
220		30	14
230		30	14
240		28	14
250		25	14
260		23	
270		20	
280		19	
290		18	
300		17	

Rill #2

Location of measurment on transect (cm)	Depth to surface from transect line (cm)		
	Bottom	Middle	Top
0	9	9	4
10	8	8	3
20	8	12	12
30	10	13	12
40	10	5	3
50	7	5	2
60	7		2
70	11		
80	11		

L – length of mound
W – width of mound
H – height of mound

Appendix 9 – Rill Measurements cont'd

Burned piñon-juniper hillslope

Rill #3

Location of measurment on transect (cm)	Depth to surface from transect line (cm)			
	Bottom	Middle	Orig. Surface	Top
0	9	6		0
10	13	6		2
20	19	4		3
30	18	4		5
40	16	9	9	0
50	13	14		0
60	13	14		0.5
70	11	17		3
80	12	10	10	4
90	9	11		4
100	10	15		0
110	12	11		0
120	14	16		
130	14	22		
140	6	19	19	
150	11	16	16	
160	10	15		
170	5	15		
180	5	18		
190		14	14	
200		18		
210		13		
220		13	13	

Rill #4

Location of measurment on transect (cm)	Depth to surface from transect line (cm)				
	Bottom	Orig. Surface	Middle Surface	Orig. Surface	Top
0	13		8		5
10	12		6		6
20	12		8		7
30	14		14		8
40			15	15	9
50			17		12
60			18		16
70			19		12
80			21		11
90	15		35		13
100	16		37		13
110	18		40		13
120	17		45		18.5
130	18		40		18
140	28		43		18.5
150	26		35		18.5
160	19		40		
170	21	21	33	33	
180	20		34		
190	21	21	28		
200	24		32		
210	25.5		26		
220	28		22		
230	24		23		
240	29		17		
250	35		15		
260	35		17		
270	34		17		
280	25		15		
290	23		16		
300	23		12		
310	20		11		
320	17		11		
330	17				

L – length of mound
W – width of mound
H – height of mound

Appendix 9 – Rill Measurements cont'd

Rill #5

Location of measurment on transect (cm)	Depth to surface from transect line (cm)					
	Bottom	Orig. Surface	Middle Surface	Orig. Surface	Top	Orig. Surface
0	8		6		12	
10	8		9		10	
20	10		6		11	
30	11		8		11	
40	12		13.5		11	
50	17		19		17	
60	15	15	11	11	20	
70	23		10		19.5	
80	14		10		17	15
90	23		13		18.5	16.5
100	27		13		15	
110	27		24		15	
120	12		22		16	
130	10		18		20	
140	10		15		20	
150	11		15		23.5	
160	11		13.5		20.5	
170			13.5		17	
180					15	
190					21	
200					27.5	
210					21	
220					20	
230					20	
240					19	
250					18	
260					17	
270					14	
280					14	

Rill #6

Location of measurment on transect (cm)	Depth to surface from transect line (cm)					
	Bottom	Orig. Surface	Middle Surface	Orig. Surface	Top	Orig. Surface
0	2		7		8	
10	5	5	6	6	11	
20	7		7		14	
30	9		16		17	
40	11		19		15	
50	12		12		14	
60	16		13		16.5	
70	20.5		8		15	
80	21		8.5	8.5	20	
90	24		8.5		18	
100	15		9		13	
110	15		10		18	
120	17		11		16	
130	15		13	13	14	
140	15		11		17	
150	16		15		17.5	
160	18		18		19	
170	14	14	16		17.5	
180	13	13	16		16	
190	14	14	14		16	
200	14		15		20	17
210	14		18		20	
220			25		12.5	
230			24		9	9
240			20			
250			23			
260			20			
270			16			

L – length of mound
W – width of mound
H – height of mound

Appendix 9 – Rill Measurements cont'd

Unburned yucca-blackbrush hillslope

Transect #1 Location of measurment on transect (cm)	Depth to surface from transect line (cm)		
	Bottom	Middle	Top
0	15	20	15
10	14	20	16
20	14	20	15
30	13	20	14
40	13	13	14
50	14	11	14
60	14	14	13
70	16	14	13
80	15	17	12
90	16	17	12
100	16	17	10
110	16	17	7
120	17	16	5
130	19	15	4
140	19	14	4
150	19	14	4
160	18	13	4
170	16	13	2
180	15	14	4
190	13	9	6
200	11	9	6
210	10	8	6
220	10	10	5
230	10	12	4
240	10	13	6
250	10	11	5
260	9.5	5	4
270	9	5	3
280	9	7	3
290	9	4	2
300	8	4	5
310	7	4	4
320	7	7	6
330	5	8	5
340	6	10	4
350	7.5	8	3
360	7	8	3
370	5	7	2
380	4	6	
390	3	6	
400	3	7	9
410			11
420			11
430			11
440			11
450			16

L – length of mound
W – width of mound
H – height of mound

Appendix 9 – Rill Measurements cont'd

Burned yucca-blackbrush hillslope

Rill #7

Location of measurment on transect (cm)	Depth to surface from transect line (cm)			
	Bottom	Middle Surface	Top	Orig. Surface
0	8	7	6	
10	8	8	7	
20	11	9	11	
30	14	14	13	
40	13.5	14	12	
50	10	20	10	
60	9.5	13	10	
70	9	15	10	
80	10	18	8	
90	11	17	9.5	
100	9	13	11	
110	8	16	14	
120	11	8	12	
130	12	10	14	14
140	17	10	16	
150	11	9.5	22	
160	13	7	20	
170	14	9.5	17	
180	14	14	16	
190	14	12	14	
200	10	14	12	
210	12	17	8	8
220	13	19	8	8
230	19	17	20	
240	16	14	19	
250	14	15	13	
260	14	17	13	
270	13	19	15	
280	13	17	12	12
290	14	10	18	
300	13	9	19	
310	14	13	28	
320	12	13	19	
330	12	12	18	
340	10	10	9	9
350	8	10	16	
360	4	10	18	
370	6	8	12	
380	9.5	7	11	
390	13	6	14	
400	10	5	16	
410	6	5	22	
420	7	8	19	
430	10	7		
440	10	9		
450				
460				

L – length of mound
W – width of mound
H – height of mound

Appendix 9 – Rill Measurements cont'd

Rill #8

Location of measurment on transect (cm)	Depth to surface from transect line (cm)			
	Bottom	Middle Surface	Top	Orig. Surface
0	5	17	22	22
10	8	17	22	
20	8	17.5	22.5	
30	11	17.5	24	
40	12	19	26	
50	14	16	29.5	
60	9.5	14.5	36	
70	20	17	35	
80	23	17.5	36	
90	13	17.5	35	
100	13	19	31	
110	19	24	33	
120	23	28	38	
130	22	22	37	
140	22	21.5	40	
150	23	18	26	26
160	19.5	17	22.5	22.5
170	20	17	24	
180	16	16.5	30	
190	14	13.5	30	
200	8	13	27.5	
210	7	13	28	
220	5	12.5	28	
230	9	12	20	
240	10	9.5	21	21
250	14	9.5	24	24
260	11		19	19
270	10		21	
280	10		28	
290	24		29	
300	24		26	
310	23		24	
320	21		27	
330	20		25	
340	20		26	
350			37	
360			25	
370			30	
380			21	21
390			20	20

L – length of mound
W – width of mound
H – height of mound

Appendix 10 – Raw Infiltrometer Data and Calculations of Infiltration Rates

		Tree	Soil pit position	Decagon #	h_1 (cm)	slope at -4 $\bar{x}$ cm/sec	Q(1) cm3/s	h_2 (cm)	slope at -1 $\bar{x}$ cm/sec	Q(2) cm3/s	Equations derived from Ankeny et al. (1991) Eq. 7 est. Q(1)	Eq. 8 est. Q(2)	Eq. 10a	Eq. 10b	attained using solver $K(h_1)$ cm/sec	$K(h_2)$ cm/sec	A 1/cm
Piñon-Juniper Hillslope	unburned	1	Upslope	1	-4	0.0046	0.070	-1	0.0148	0.225	6.99E-02	2.25E-01	-1.10E-02	-1.10E-02	1.73E-03	5.58E-03	0.350
				2	-4	0.00398	0.061	-1	0.0127	0.193	6.05E-02	1.93E-01	-9.41E-03	-9.39E-03	1.49E-03	4.77E-03	0.348
				3	-4	0.0053	0.081	-1	0.0194	0.295	8.06E-02	2.95E-01	-1.47E-02	-1.47E-02	2.10E-03	7.69E-03	0.380
			Interspace	1	-4	0.0021	0.032	-1	0.0111	0.169	3.19E-02	1.69E-01	-8.71E-03	-8.71E-03	9.23E-04	4.88E-03	0.454
				2	-4	0.0005	0.008	-1	0.009	0.137	7.60E-03	1.37E-01	-7.23E-03	-7.23E-03	2.54E-04	4.57E-03	0.596
				3	-4	0.0023	0.035	-1	0.0119	0.181	3.50E-02	1.81E-01	-9.33E-03	-9.32E-03	1.01E-03	5.21E-03	0.450
		2	Upslope	1	-4	0.0049	0.075	-1	0.0116	0.176	7.45E-02	1.76E-01	-7.89E-03	-7.87E-03	1.56E-03	3.69E-03	0.270
				2	-4	0.0116	0.176	-1	0.0106	0.161	2.21E-01	2.62E-01	-4.25E-03	-4.22E-03	*1.29E-03*	*1.53E-03*	*0.056*
				3	-4	0.0062	0.094	-1	0.0148	0.225	9.43E-02	2.25E-01	-1.01E-02	-1.01E-02	1.99E-03	4.74E-03	0.273
			Interspace	1	-4	0.0034	0.052	-1	0.0051	0.078	5.17E-02	7.76E-02	-2.39E-03	-2.40E-03	6.40E-04	9.60E-04	0.134
				2	-4	0.0048	0.073	-1	0.0097	0.147	7.30E-02	1.48E-01	-6.09E-03	-6.09E-03	1.34E-03	2.72E-03	0.225
				3	-4	0.0011	0.017	-1	0.0101	0.154	1.67E-02	1.54E-01	-8.08E-03	-8.07E-03	5.28E-04	4.85E-03	0.535
		3	Upslope	1	-4	0.0004	0.006	-1	0.0461	0.701	6.08E-03	7.01E-01	-3.70E-02	-3.70E-02	2.12E-04	2.45E-02	0.655
				2	-4	0.0007	0.011	-1	0.0265	0.403	1.06E-02	4.03E-01	-2.13E-02	-2.13E-02	3.66E-04	1.38E-02	0.632
				3	-4	0.0031	0.047	-1	0.0107	0.163	4.71E-02	1.63E-01	-8.04E-03	-8.03E-03	1.20E-03	4.15E-03	0.367
			Interspace	1	-4	0.0019	0.029	-1	0.0083	0.126	2.89E-02	1.26E-01	-6.43E-03	-6.41E-03	7.96E-04	3.48E-03	0.417
				2	-4	0.0002	0.003	-1	0.0109	0.166	3.04E-03	1.66E-01	-8.76E-03	-8.76E-03	1.05E-04	5.74E-03	0.643
				3	-4	0.0018	0.027	-1	0.0206	0.313	2.74E-02	3.13E-01	-1.65E-02	-1.65E-02	8.84E-04	1.01E-02	0.559
		4	Upslope	1	-4	0.008	0.122	-1	-0.0002	-0.003	1.21E-01	-4.30E-03	1.61E-04	-1.13E-02	*7.85E-03*	-2.80E-04	50.453
				2	-4	0.002	0.030	-1	0.0082	0.125	3.04E-02	1.25E-01	-6.31E-03	-6.29E-03	8.22E-04	3.37E-03	0.404
				3	-4	0.0015	0.023	-1	0.0036	0.055	2.28E-02	5.47E-02	-2.46E-03	-2.46E-03	4.82E-04	1.16E-03	0.274
			Interspace	1	-4	0.0043	0.065	-1	0.0069	0.105	6.54E-02	1.05E-01	-3.54E-03	-3.54E-03	9.07E-04	1.45E-03	0.155
				2	-4	0.0089	0.135	-1	0.0086	0.131	1.63E-01	2.13E-01	-4.85E-03	-4.86E-03	1.41E-03	1.83E-03	0.087
				3	-4	0.0077	0.117	-1	0.0162	0.246	1.17E-01	2.46E-01	-1.04E-02	-1.04E-02	2.23E-03	4.70E-03	0.237
	Burned	5	Upslope	1	-4	0.0017	0.026	-1	0.0054	0.082	2.58E-02	8.21E-02	-4.00E-03	-3.99E-03	6.37E-04	2.02E-03	0.347
				2	-4	0.0037	0.056	-1	0.0115	0.175	5.63E-02	1.75E-01	-8.47E-03	-8.47E-03	1.37E-03	4.27E-03	0.342
				3	-4	0.0061	0.093	-1	0.0067	0.102	1.11E-01	2.03E-01	-7.80E-03	-7.78E-03	1.84E-03	3.35E-03	0.194
			Interspace	1	-4	0.0089	0.135	-1	0.0156	0.237	1.35E-01	2.37E-01	-8.83E-03	-8.71E-03	2.11E-03	3.70E-03	0.180
				2	-4	0.000005	0.000	-1	0.0128	0.195	7.58E-05	1.95E-01	-1.03E-02	-1.03E-02	2.67E-06	6.85E-03	0.666
				3	-4	0.0002	0.003	-1	0.0104	0.158	3.04E-03	1.58E-01	-8.36E-03	-8.36E-03	1.05E-04	5.47E-03	0.641
		6	Upslope	1	-4	0.003	0.046	-1	0.0104	0.158	4.56E-02	1.58E-01	-7.82E-03	-7.81E-03	1.17E-03	4.04E-03	0.368
				2	-4	0.0043	0.065	-1	0.0067	0.102	6.54E-02	1.02E-01	-3.32E-03	-3.31E-03	8.62E-04	1.34E-03	0.145
				3	-4	0.005	0.076	-1	0.0056	0.085	7.61E-02	8.54E-02	-9.83E-04	-1.10E-03	*3.46E-04*	3.88E-04	0.043
			Interspace	1	-4	0.0007	0.011	-1	0.0034	0.052	1.06E-02	5.17E-02	-2.66E-03	-2.65E-03	3.01E-04	1.46E-03	0.437
				2	-4	0.0012	0.018	-1	0.0024	0.036	1.83E-02	3.65E-02	-1.50E-03	-1.49E-03	3.30E-04	6.60E-04	0.220
				3	-4	0.0015	0.023	-1	0.0036	0.055	2.28E-02	5.47E-02	-2.46E-03	-2.46E-03	4.82E-04	1.16E-03	0.274
		7	Upslope	1	-4	0.0053	0.081	-1	0.0127	0.193	1.20E-01	2.22E-01	-8.63E-03	-8.60E-03	2.02E-03	3.72E-03	0.197
				2	-4	0.0034	0.052	-1	0.0087	0.132	5.17E-02	1.32E-01	-6.09E-03	-6.08E-03	1.14E-03	2.91E-03	0.291
				3	-4	0.005	0.076	-1	0.0096	0.146	7.61E-02	1.46E-01	-5.84E-03	-5.81E-03	1.33E-03	2.55E-03	0.209
			Interspace	1	-4	0.0034	0.052	-1	0.0067	0.102	5.17E-02	1.02E-01	-4.15E-03	-4.12E-03	9.25E-04	1.82E-03	0.216
				2	-4	0.0044	0.067	-1	0.0096	0.146	6.69E-02	1.46E-01	-6.29E-03	-6.29E-03	1.32E-03	2.88E-03	0.248
				3	-4	0.0032	0.049	-1	0.0079	0.120	4.87E-02	1.20E-01	-5.47E-03	-5.44E-03	1.05E-03	2.58E-03	0.281
		8	Upslope	1	-4	0.0101	0.154	-1	0.0061	0.093	1.97E-01	2.26E-01	-3.05E-03	-3.46E-03	1.07E-03	1.23E-03	0.052
				2	-4	0.0044	0.067	-1	0.0059	0.090	6.69E-02	8.98E-02	-2.24E-03	-2.15E-03	6.11E-04	8.20E-04	0.093
				3	-4	0.0022	0.033	-1	0.0092	0.140	3.34E-02	1.40E-01	-7.09E-03	-7.08E-03	9.11E-04	3.81E-03	0.409
			Interspace	1	-4	0.0022	0.033	-1	0.0071	0.108	3.35E-02	1.08E-01	-5.27E-03	-5.26E-03	8.30E-04	2.68E-03	0.351
				2	-4	0.0034	0.052	-1	0.0046	0.070	5.17E-02	6.99E-02	-1.77E-03	-1.73E-03	4.90E-04	6.62E-04	0.097
				3	-4	0.0065	0.099	-1	0.0077	0.117	1.18E-01	1.47E-01	-2.96E-03	-2.99E-03	8.87E-04	1.11E-03	0.075
Yucca-Blackbrush Hillslope		9	Upslope	1	-4	0.0047	0.071	-1	0.0083	0.126	7.15E-02	1.26E-01	-4.72E-03	-4.69E-03	1.13E-03	2.00E-03	0.183
				2	-4	0.0062	0.094	-1	0.0148	0.225	9.43E-02	2.25E-01	-1.01E-02	-1.01E-02	1.99E-03	4.74E-03	0.273
				3	-4	0.0058	0.088	-1	0.0096	0.146	8.82E-02	1.46E-01	-5.12E-03	-5.11E-03	1.28E-03	2.12E-03	0.164
			Interspace	1	-4	0.0045	0.068	-1	0.0075	0.114	6.84E-02	1.14E-01	-4.03E-03	-3.99E-03	9.99E-04	1.66E-03	0.165
				2	-4	0.0064	0.097	-1	0.0118	0.179	9.73E-02	1.79E-01	-6.97E-03	-6.93E-03	1.62E-03	2.99E-03	0.197
				3	-4	0.0047	0.071	-1	0.0077	0.117	7.15E-02	1.17E-01	-4.06E-03	-4.03E-03	1.02E-03	1.67E-03	0.160
		10	Upslope	1	-4	0.0035	0.053	-1	0.0066	0.100	5.32E-02	1.00E-01	-3.97E-03	-3.94E-03	9.09E-04	1.72E-03	0.203
				2	-4	0.0026	0.040	-1	0.0071	0.108	3.95E-02	1.08E-01	-5.07E-03	-5.06E-03	9.05E-04	2.47E-03	0.309
				3	-4	0.0018	0.027	-1	0.0073	0.111	2.74E-02	1.11E-01	-5.61E-03	-5.60E-03	7.38E-04	2.99E-03	0.402
			Interspace	1	-4	-0.0005	-0.008	-1	0.0087	0.132	7.85E-02	1.83E-01	-8.14E-03	-8.13E-03	1.63E-03	3.79E-03	0.266
				2	-4	-0.0011	-0.017	-1	0.0079	0.120	6.81E-02	1.30E-01	-5.16E-03	-5.16E-03	1.18E-03	2.26E-03	0.208

Appendix 10 – Raw Infiltrometer Data and Calculations of Infiltration Rates cont'd

		Tree	Soil pit position	Decagon #	$K(h_1)$ cm/sec	$K(h_2)$ cm/sec	A 1/cm	SumSq.	K(-4)	stdev.	K(-1)	stdev.	A	stdev.
Piñon-Juniper Hillslope	Unburned	1	Upslope	1	1.73E-03	5.58E-03	0.350	3.84E-10	1.78E-03	3.1E-04	6.01E-03	1.5E-03	0.359	0.02
				2	1.49E-03	4.77E-03	0.348	5.22E-10						
				3	2.10E-03	7.69E-03	0.380	2.79E-10						
			Interspace	1	9.23E-04	4.88E-03	0.454	6.11E-11	7.28E-04	4.1E-04	4.89E-03	3.2E-04	0.500	0.08
				2	2.54E-04	4.57E-03	0.596	1.90E-12						
				3	1.01E-03	5.21E-03	0.450	6.72E-11						
		2	Upslope	1	1.56E-03	3.69E-03	0.270	6.50E-10	1.77E-03	3.0E-04	3.32E-03	1.6E-03	0.200	0.12
				2	1.29E-03	1.53E-03	*0.056*	1.21E-02						
				3	1.99E-03	4.74E-03	0.273	2.91E-10						
			Interspace	1	6.40E-04	9.60E-04	0.134	7.56E-10	8.38E-04	4.4E-04	2.84E-03	1.9E-03	0.298	0.21
				2	1.34E-03	2.72E-03	0.225	2.47E-10						
				3	5.28E-04	4.85E-03	0.535	1.59E-10						
		3	Upslope	1	2.12E-04	2.45E-02	0.655	1.96E-12	5.94E-04	5.3E-04	4.15E-03	n/a	0.551	0.16
				2	3.66E-04	1.38E-02	0.632	2.05E-11						
				3	1.20E-03	4.15E-03	0.367	1.90E-10						
			Interspace	1	7.96E-04	3.48E-03	0.417	3.06E-10	5.95E-04	4.3E-04	6.45E-03	3.4E-03	0.540	0.11
				2	1.05E-04	5.74E-03	0.643	1.94E-12						
				3	8.84E-04	1.01E-02	0.559	1.64E-10						
	Burned	4	Upslope	1	7.85E-03	-2.80E-04	50.453	1.35E-04	6.52E-04	2.4E-04	2.26E-03	1.6E-03	17.044	28.93
				2	8.22E-04	3.37E-03	0.404	3.94E-10						
				3	4.82E-04	1.16E-03	0.274	2.14E-10						
			Interspace	1	9.07E-04	1.45E-03	0.155	5.13E-10	1.52E-03	6.7E-04	2.66E-03	1.8E-03	0.159	0.07
				2	1.41E-03	1.83E-03	0.087	7.49E-03						
				3	2.23E-03	4.70E-03	0.237	1.60E-09						
		5	Upslope	1	6.37E-04	2.02E-03	0.347	9.33E-11	1.28E-03	6.0E-04	3.21E-03	1.1E-03	0.294	0.09
				2	1.37E-03	4.27E-03	0.342	1.69E-10						
				3	1.84E-03	3.35E-03	0.194	1.05E-02						
			Interspace	1	2.11E-03	3.70E-03	0.180	1.68E-08	7.39E-04	1.2E-03	5.34E-03	1.6E-03	0.496	0.27
				2	2.67E-06	6.85E-03	0.666	5.03E-14						
				3	1.05E-04	5.47E-03	0.641	4.77E-12						
		6	Upslope	1	1.17E-03	4.04E-03	0.368	5.70E-11	1.17E-03	n/a	1.92E-03	1.9E-03	0.185	0.17
				2	8.62E-04	1.34E-03	0.145	5.50E-10						
				3	3.46E-04	3.88E-04	0.043	1.15E-07						
			Interspace	1	3.01E-04	1.46E-03	0.437	2.91E-10	3.71E-04	9.7E-05	1.09E-03	4.0E-04	0.310	0.11
				2	3.30E-04	6.60E-04	0.220	4.12E-10						
				3	4.82E-04	1.16E-03	0.274	2.14E-10						

		Tree	Soil pit position	Decagon #	$K(h_1)$	$K(h_2)$	A	SumSq.	K(-4)	stdev.	K(-1)	stdev.	A	stdev.
Yucca-Blackbrush Hillslope	Burned	7	Upslope	1	2.02E-03	3.72E-03	0.197	2.45E-03	1.49E-03	4.6E-04	3.06E-03	6.0E-04	0.233	0.05
				2	1.14E-03	2.91E-03	0.291	5.21E-10						
				3	1.33E-03	2.55E-03	0.209	2.27E-09						
			Interspace	1	9.25E-04	1.82E-03	0.216	2.14E-09	1.10E-03	2.0E-04	2.43E-03	5.4E-04	0.248	0.03
				2	1.32E-03	2.88E-03	0.248	1.23E-10						
				3	1.05E-03	2.58E-03	0.281	7.79E-10						
		8	Upslope	1	1.07E-03	1.23E-03	0.052	1.97E-02	7.61E-04	2.1E-04	1.95E-03	1.6E-03	0.185	0.20
				2	6.11E-04	8.20E-04	0.093	1.39E-08						
				3	9.11E-04	3.81E-03	0.409	5.58E-11						
			Interspace	1	8.30E-04	2.68E-03	0.351	2.50E-10	7.36E-04	2.1E-04	1.48E-03	1.1E-03	0.174	0.15
				2	4.90E-04	6.62E-04	0.097	2.17E-09						
				3	8.87E-04	1.11E-03	0.075	1.27E-03						
		9	Upslope	1	1.13E-03	2.00E-03	0.183	9.68E-10	1.47E-03	4.6E-04	2.95E-03	1.5E-03	0.207	0.06
				2	1.99E-03	4.74E-03	0.273	2.91E-10						
				3	1.28E-03	2.12E-03	0.164	9.17E-10						
			Interspace	1	9.99E-04	1.66E-03	0.165	2.11E-09	1.21E-03	3.6E-04	2.11E-03	7.7E-04	0.174	0.02
				2	1.62E-03	2.99E-03	0.197	3.22E-09						
				3	1.02E-03	1.67E-03	0.160	3.23E-09						
	Unburned	10	Upslope	1	9.09E-04	1.72E-03	0.203	2.13E-09	8.51E-04	9.8E-05	2.39E-03	6.4E-04	0.305	0.10
				2	9.05E-04	2.47E-03	0.309	6.23E-11						
				3	7.38E-04	2.99E-03	0.402	1.45E-10						
			Interspace	1	1.63E-03	3.79E-03	0.266	1.00E-02	1.37E-03	2.3E-04	2.94E-03	7.8E-04	0.237	0.03
				2	1.18E-03	2.26E-03	0.208	7.30E-03						
				3	1.30E-03	2.76E-03	0.238	9.49E-03						
		11	Upslope	1	6.37E-04	1.05E-03	0.163	2.71E-09	6.71E-04	1.4E-04	1.51E-03	4.8E-04	0.242	0.12
				2	8.21E-04	1.45E-03	0.184	3.42E-10						
				3	5.54E-04	2.02E-03	0.379	1.35E-10						
			Interspace	1	1.15E-03	5.32E-03	0.429	1.28E-10	1.37E-03	3.0E-04	3.93E-03	1.4E-03	0.305	0.11
				2	1.70E-03	4.05E-03	0.272	1.42E-02						
				3	1.25E-03	2.43E-03	0.214	8.47E-03						
		12	Upslope	1	8.78E-04	1.11E-03	0.082	3.15E-03	7.82E-04	2.3E-04	1.72E-03	7.1E-04	0.226	0.19
				2	5.16E-04	2.49E-03	0.437	2.97E-10						
				3	9.51E-04	1.56E-03	0.160	2.39E-09						
			Interspace	1	1.07E-03	4.41E-03	0.406	1.78E-10	1.39E-03	6.72E-04	5.72E-03	2.46E-03	4.43E-01	5.01E-02
				2	2.16E-03	8.56E-03	0.500	1.59E-02						
				3	9.30E-04	4.18E-03	0.423	2.95E-10						

values were not included in final calculations of infiltration rates
n/a = not applicable

Appendix 10 – Raw Infiltrometer Data and Calculations of Infiltration Rates cont'd

Average Infiltration rate at each upslope and interspace location on each hillslope

Site	Soil pit position	K(-4) cm/sec	stdev.	K(-1) cm/sec	stdev.	A	stdev.
Piñon-Juniper Hillslope - Unburned	Upslope	0.001332	0.000703	0.0045925	0.001872	0.370155	0.183345
	Interspace	0.00072	0.000385	0.0047247	0.002505	0.446082	0.169155
Piñon-Juniper Hillslope - Burned	Upslope	0.001026	0.000468	0.0024931	0.001455	0.264605	0.126105
	Interspace	0.000876	0.000851	0.0030311	0.002215	0.321799	0.211292
Yucca-Blackbrush Hillslope - Unburned	Upslope	0.001275	0.000462	0.0026558	0.001275	0.227571	0.095908
	Interspace	0.001015	0.000316	0.002006	0.000821	0.198773	0.087175
Yucca-Blackbrush Hillslope - Burned	Upslope	0.000768	0.000164	0.0018733	0.000669	0.257605	0.126681
	Interspace	0.001375	0.000385	0.0041964	0.001918	0.271184	0.081799

Site		K(-4) cm/hr	stdev.	K(-1) cm/hr	stdev.	A	stdev.
Piñon-Juniper Hillslope - Unburned	Upslope	4.794667	2.532405	16.533173	6.740404	0.370155	0.183345
	Interspace	2.593035	1.385368	17.00892	9.019253	0.446082	0.169155
Piñon-Juniper Hillslope - Burned	Upslope	3.692229	1.683215	8.9751318	5.238176	0.264605	0.126105
	Interspace	3.151933	3.063105	10.912043	7.975298	0.321799	0.211292
Yucca-Blackbrush Hillslope - Unburned	Upslope	4.589513	1.664477	9.5610231	4.591474	0.227571	0.095908
	Interspace	3.654155	1.136802	7.2216457	2.955536	0.198773	0.087175
Yucca-Blackbrush Hillslope - Burned	Upslope	2.76414	0.590023	6.7437799	2.410145	0.257605	0.126681
	Interspace	4.949515	1.384508	15.106955	6.905492	0.271184	0.081799

Appendix 11 – Cs-137 Results

Lab Id	Site Location	Sample Weigt (g)	count per run	std. dev. (%)	std. dev. 1 sigma	adjusted for anayzer	Bq/s	pCi	pCi/g	notes
07-406	YBB burned Toe1 0-5	31.90	41.00	20.55	0.06	1138.89	0.32	8.55	0.27	1 @ 600; 9 @1200; 18@2000;
07-407	YBB burned Toe1 5-10	31.23	22.00	42.83	0.09	611.11	0.25	6.88	0.22	3 @600;11@1200;6@1800;12@2400
07-408	YBB burned Toe1 10-15	34.12	41.00	20.85	0.05	1138.89	0.32	8.55	0.25	
07-408B	YBB burned Toe1 10-15	25.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 1200
07-409	YBB burned Toe1 15-20	28.74	12.00	61.47	0.05	333.33	0.09	2.50	0.09	
07-410	YBB burned Toe1 20-25	32.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
07-411	YBB burned Toe1 25-30	29.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
07-412	YBB burned Toe2 0-5	33.76	4.75	110.60	0.03	131.94	0.04	0.99	0.03	
07-413	YBB burned Toe2 5-10	32.57	10.50	58.65	0.04	291.67	0.08	2.19	0.07	
07-414	YBB burned Toe210-15	30.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 700
07-415	YBB burned Toe215-20	27.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 850
07-416	YBB burned Toe2 20-25	37.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-417	YBB burned Toe2 25-30	38.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 1200
07-418	Cs- baseline 1 0-5	30.44	11.00	73.77	0.06	305.56	0.08	2.29	0.08	
07-419	Cs- baseline 1 5-10	24.22	15.00	47.82	0.06	416.67	0.12	3.13	0.13	
07-420	Cs- baseline 10-15	40.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ran for 1300 sec. still 0
07-421	Cs- baseline 1 15-20	31.52	1.00	862.89	0.07	27.78	0.01	0.27	0.01	stopped running @ 2800
07-422	Cs- baseline 1 20-25	32.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-423	Cs- baseline 1 25-30	32.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-424	Cs- baseline 2 0-5	31.94	11.00	77.92	0.06	305.56	0.08	2.29	0.07	
07-425	Cs- baseline 2 5-10	26.84	33.00	29.01	0.07	916.67	0.25	6.88	0.26	
07-426	Cs- baseline 2 10-15	30.56	2.00	131.54	0.05	55.56	0.05	1.25	0.04	stopped running @ 1200
07-427	Cs- baseline 2 15-20	31.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-428	Cs- baseline 2 20-25	31.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-429	Cs- baseline 2 25-30	26.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-430	Pit #6 0-5	30.03	75.00	14.08	0.07	2083.33	0.58	15.64	0.52	
07-431	Pit #6 5-10	29.94	50.00	21.10	0.07	1388.89	0.39	10.43	0.35	
07-432	Pit #6 10-15	26.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
07-433	Pit #6 15-20	29.59	10.00	46.74	0.08	277.78	0.20	5.36	0.18	stopped running @ 1400
07-434	Pit #6 20-25	25.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-435	Pit #6 25-30	25.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-437	Pit #13 0-5	23.58	40.00	22.00	0.08	1111.11	0.31	8.34	0.35	
07-438	Pit #13 5-10	27.40	27.00	31.00	0.06	750.00	0.21	5.63	0.21	
07-439	Pit #13 10-15	23.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-444	Pit #15 0-5	32.42	22.00	28.36	0.08	611.11	0.34	9.18	0.28	stopped running @ 1800
07-445	Pit #15 5-10	32.00	10.00	53.61	0.05	277.78	0.12	3.13	0.10	stopped running @ 2400
07-446	Pit #15 10-15	22.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-450	Pit #17 0-5	27.89	85.00	14.17	0.09	2361.11	0.66	17.73	0.64	
07-451	Pit #17 5-10	21.93	13.00	68.26	0.08	361.11	0.10	2.71	0.12	
07-452	Pit #17 10-15	25.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-456	Pit #31 0-5	34.52	66.00	15.83	0.06	1833.33	0.51	13.76	0.40	
07-457	Pit #31 5-10	38.57	39.00	26.29	0.06	1083.33	0.30	8.13	0.21	
07-458	Pit #31 10-15	25.31	16.00	45.31	0.06	444.44	0.12	3.34	0.13	
07-462	Pit #33 0-5	36.43	28.00	29.91	0.05	777.78	0.22	5.84	0.16	
07-463	Pit #33 5-10	29.17	12.00	65.77	0.06	333.33	0.09	2.50	0.09	
07-464	Pit #33 10-15	37.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
07-467	Pit #43 0-5	26.43	15.00	53.51	0.06	416.67	0.12	3.13	0.12	
07-468	Pit #43 5-10	35.42	44.00	21.97	0.06	1222.22	0.34	9.18	0.26	
07-469	Pit #43 10-15	31.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 800
07-473	Pit #45 0-5	22.92	23.00	35.13	0.07	638.89	0.18	4.80	0.21	
07-474	Pit #45 5-10	28.94	4.00	122.20	0.11	111.11	0.09	2.50	0.09	stopped running @ 1200
07-475	Pit #45 10-15	23.39	4.00	206.87	0.44	111.11	0.19	5.01	0.21	
				Colluvial Apron from Providence Mountain Granite Basin						
06-831	Colluvial Apron	38.74	36.00	23.47	0.07	1000.00	0.41	10.99	0.28	stopped running @ 2460
06-832	Colluvial Apron	30.15	15.00	35.53	0.11	416.67	0.35	9.38	0.31	stopped running @ 1200
06-832B	Colluvial Apron	34.01	13.00	38.29	0.09	361.11	0.30	8.13	0.24	stopped running @ 1200
06-833	Colluvial Apron	26.92	3.00	131.54	0.09	83.33	0.07	1.88	0.07	stopped running @ 1200
06-833B	Colluvial Apron	24.23	0.00		0.00	0.00	0.00	0.00	0.00	stopped running @ 600
06-834	Colluvial Apron	22.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
06-835	Colluvial Apron	35.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600
06-836	Colluvial Apron	34.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	stopped running @ 600

All samples run for one hour unless otherwise noted
any samples that had a reading of 0 at 600 sec. were stopped
any samples that had a reading of <5 at 1200 sec. were stopped
any samples that had a reading of <10 at 2400 sec. were stopped
B denotes samples that were < 1mm; all other samples were <2 mm